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LETTER OF TRANSMITTAL

To the Hon. David E. Fitzgerald,
Mayor of the City of New Haven,

Dear Sir:

The present method of disposing of the sewage of New Haven, by discharging the untreated liquid from shore outfalls above low water, has for many years been the cause of dissatisfaction to sanitary authorities and to citizens familiar with our harbor problem. In 1910 the State Board of Health reported upon the condition of the harbor waters in connection with the possible menace to the local shellfish industry. In 1915 the United States Bureau of Chemistry studied the question and arrived at the conclusion that the harbor waters were so polluted that no oysters for sale in interstate commerce should be grown in the area marked by a line connecting Morgan Point on the east with Oyster River Point on the west and passing through the breakwater, unless such oysters were purified by transplanting them in non-polluted waters for at least seven days before shipment. In the succeeding year, 1916, a corps of experts from the U. S. Public Health Service conducted another exhaustive investigation which led Dr. H. S. Cumming, the Surgeon in Charge to report:

"That the harbor of New Haven, and the tidal portions of the Quinnipiac, West and Mill Rivers above the line between Bradley Point and the Old Tower are grossly polluted by sewage discharged from the sewer outfalls in the harbor."

Dr. Cumming reported that "Shellfish in the harbor are exposed to pollution by sewage from the city and are filthy, dangerous and unfit to be eaten as taken from the area;" and that "Bathing and swimming in the waters of the harbor above the line between Old Tower and Bradley Point and in the rivers is unsafe and should be prohibited." Evidence was obtained that fresh sewage pollution reaches even to Fort Hale and Morris Cove and Cox's Beach. Dr. Cumming recommended "That the taking of shellfish from the harbor of New Haven be prohibited, except under

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reported in city sewage, and one which we found to exert so important an influence on certain processes as to make their use with this sewage quite out of the question. Tests of certain of the more promising processes of sewage treatment were also made on the Boulevard sewer, as a type of those sewers of the city which discharge ordinary domestic sewages free from industrial wastes.

Altogether six different major processes of sewage treatment were studied; fine screening, plain sedimentation, Imhoff tank treatment, activated sludge treatment, chlorination, and the Miles acid process, with minor modifications of each. Over 1,000 samples of sewage, effluent and sludge, were submitted to chemical analysis and over 1,000 more were examined bacteriologically. The results of our experiments, which were brought to a close in May, 1918, have now been thoroughly considered and compared; and they furnish, as we believe, a sound basis for a conclusion as to the next step to be taken in dealing with the sewage problem of New Haven.

Like all previous investigators of this problem we are convinced that the present method of discharging untreated sewage into the harbor is productive of serious nuisance and is a menace to the health of the community. The conditions are becoming intensified year by year with the increasing sewage flow and are bound before long to become intolerable.

So far as the local nuisance created by the spreading out of sewage liquids and the deposition of sewage solids on the flats of the upper harbor is concerned, the best remedy seems to us to be the discharge of the sewage into the deep dredged channels of the harbor, which would necessitate the construction of long outfall sewers at the Meadow and Sea Street outfalls. The attempt to remedy such conditions by digging lateral channels from a shore outfall to the main channel is only a palliative measure and has not yielded satisfactory results, as applied at the Sea Street outfall.

The discharge of the sewage by submerged outlets into the main channels of the harbor, will go far toward remedying the offensive conditions which now obtain along the foreshores. If the sewage were discharged untreated, however, from such submerged outlets there would be danger of the sludging up of the channels themselves and polluting elements in the sewage would be carried down the harbor to the bathing beaches and the oyster beds even more promptly than is the case at present.

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We believe, therefore, that, while such elaborate purification of sewage as has been found necessary in many inland cities would be superfluous at New Haven, it will be essential to so treat the sewage before discharge that a substantial proportion of its suspended solid material and a large majority of its potentially dangerous intestinal bacteria shall be removed. In view of the necessity for locating disposal plants in thickly settled districts it is obvious that very special precautions must be taken to avoid any possibility of the producton of offensive odors in their immediate vicinity.

With these fundamental limitations in mind, and in view of the results obtained in the experimental treatment of the East Street and Boulevard sewages, and of various local conditions affecting costs of construction, we have concluded that the only processes to be recommended for the treatment of New Haven sewage are Miles acid treatment or Imhoff tank treatment followed by chlorination. The space needed for filtration is not available. Fine screening in our experiments did not effect a sufficient removal of suspended solids to meet the needs of the case; and activated sludge treatment, we find, cannot be used at all with the East Street sewage containing its industrial wastes.

In the Miles acid process, the sewage is treated with sulphurous acid in the form of sulphur dioxide and then allowed to flow slowly through a tank in which its solid matters settle out. The acid effects a high degree of disinfection of the sewage and precipitates out a large proportion of its solid material, forming a sludge from which grease and nitrogen can later be recovered. Above all, the process is far freer from any danger of possible nuisance than any other with which we are familiar, on account of the fact that putrefaction in both tank liquor and sludge is checked by the sulphurous acid. This fact has seemed to us of very special importance under the conditions which must govern the location of disposal plants about New Haven harbor. With the East Street sewage even the Imhoff process is seriously hampered by the antiseptic industrial wastes, so that at this outfall the Miles process is the only one that can be intalled with reasonable certainty of inoffensive operation.

The acid process of treating sewage is a new one, never yet applied to city sewage in America on a practical scale, though a very similar procedure has been in use for years at Bradford, England. We believe however that the results obtained make its successful operation certain from a sanitary standpoint. The economy of the

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process is necessarily somewhat problematical since it depends on the cost of drying and degreasing the sludge and on the potential revenue to be obtained from the sale of grease and fertilizer. On this point we have made careful and, we believe, conservative estimates of the gross and net cost of treatment at the East Street and Sea Street outfalls by the Miles process, and by Imhoff tank treatment, and by fine screening, in the latter cases to be followed by chlorination. We find the net cost of the Miles process to be materially less, both at the East Street outfall, ($8.41 per million gallons of sewage treated against $11.99 for Imhoff tanks and $11.03 for screening) and at the Sea Street outfall ($9.60 against $12.14 for Imhoff treatment and $12.35 for screening).

The total annual cost of treatment at the East Street outfall, according to our estimates (based on a flow of 15 million gallons) should be approximately $46,000 a year, including all interest and depreciation charges as well as operating expenses.

A special feature of importance to be considered in connection with the possible adoption of the Miles acid process is the fact that this process permits the recovery of grease, glycerin and fertilizing materials, the utilization of which has been made a patriotic duty by the demands of the war. The need for these commodities is likely to remain an urgent one for some time after the war is over; and New Haven by installing a process of this kind can play an important part in the great task of national conservation.

In view of all the facts stated we feel that the process of Miles acid treatment can be recommended as best suited for the East Street outfall and will probably prove most satisfactory for the other outfalls as well. We believe that it would be best to proceed first with the former installation, where Miles acid treatment is the only one which promises successful sanitary results, and to make a final decision as to the relative economic availability of the acid process and Imhoff tank treatment followed by chlorination for the other outfalls after experience has been obtained at East Street on a practical scale.

We therefore recommend that detailed plans and estimates be prepared for a Miles acid treatment plant at the East Street outfall; and that this installation be completed as soon as possible. If operation of the East Street plant proves economical the same system should be extended to the other outfalls. If it does not, Imhoff

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treatment, followed by chlorination, should be adopted for the treatment of the sewage from Sea Street, Meadow and State Streets, James Street, and Poplar Street.

At a still later date the problem of the small isolated sewers, now discharging five million gallons of sewage into the harbor outside of the five main outfalls, must of course also receive consideration; and in planning for disposal works the treatment of this additional sewage flow should be provided for.

The problem of the disposal of the sewage of New Haven is a large and a difficult one, which must be solved step by step during a period of years. We are convinced that the first step is the construction of a treatment plant of the type recommended at the East Street outfall; and we respectfully urge upon you the importance of taking without delay the first steps toward restoration of the purity of the harbor, which should be made once more a source of pride and prosperity to the city of New Haven instead of a local nuisance and a menace to the public health.

C.-E. A. WINSLOW, Chairman
S. E. BARNEY
A. B. HILL
J. W. MURPHY
F. S. NELSON
H. B. SARGENT

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REPORT ON THE SEWAGE DISPOSAL PROBLEM OF NEW HAVEN

C.-E. A. Winslow, D.P.H.

Professor of Public Health, Yale School of Medicine

and

F. W. Mohlman, Ph.D.

Chemist, New Haven Experiment Station

THE SEWAGE DISPOSAL PROBEM OF NEW HAVEN

The city of New Haven occupies an area of 11,460 acres, to the north and along the east shore, of New Haven harbor. It is situated on a generally level plain, with ranges of hills on the east and west, close to the city, and on the north, at a slightly greater distance. The soil is sandy, the underlying rock deposits lying from one to two hundred feet below the surface.

The population of the city was 133,605 in the last census year, 1910. Using the census method of arithmetical progression it would be estimated at 154,800 for July 1, 1918. This figure however is undoubtedly too low, since the development of munition industries has been very rapid during the past four years. The City Health Department estimates the 1918 population at 160,000. The State Health Department places it at 161,000.

The general plan of the main trunk sewers of the city is indicated in Fig. 1. The system included, Jan. 1, 1918, 133 miles of sewers and it is estimated that there are about 20,000 connections. The system is built on the combined plan to take both house sewage and storm water, and the sewers, though old, are well designed and in general adequate and satisfactory. An important extension of the system is at present under construction to serve the northern section of the Westville district.

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There are five large public outfall sewers which discharge into New Haven harbor at the points indicated on Fig. 1. The volume of flow as determined from gaugings made during August, 1916, under the direction of Mr. A. B. Hill, and the volumes estimated by Mr. C. N. Harrub of the U. S. Public Health Service in 1917, are indicated in Table I.

TABLE I. Volume of New Haven Sewage.

Outfall.	Flow in Gallons Per Day. As Measured August, 1916.	As Estimated by C. N. Harrub, 1917.
Sea Street	3,632,000	6,000,000
Meadow and State Streets*	2,249,000	4,500,000
East Street	15,598,000	14,000,000
Poplar Street	847,000	2,000,000
James Street	2,449,000	3,000,000
Total	24,775,000	29,500,000

*Two separate main sewers discharge at this point, but they are so close together that we have dealt with them as one.

As a result of a survey conducted for the U. S. Public Health Service in 1917 Mr. Harrub points out that in addition to the five outlets discussed above there are fourteen storm water overflows which discharge into the rivers or harbor. He estimates that 225,000 gallons of sewage a day enter the Quinnipiac River from private sewers, in addition to the contribution of the Poplar and James Street outfalls; that 298,000 gallons enter Mill River; that 3,756,000 gallons enter West River (chiefly dye house and paper mill waste); and that 865,000 gallons are contributed directly by industrial plants on the harbor (principally from a slaughter house and a hardware plant). The total contribution of sewage from sources other than those listed in Table I would therefore be 5,144,000 gallons or 16 per cent of the total discharge of the five public sewers.

The water supply of the city is derived from surface sources and is provided by a private water company. It is unmetered and the waste of water is great, the per capita consumption being about 180 gallons per day. From this fact it is obvious that a highly dilute sewage is to be anticipated.

New Haven is to a considerable extent an industrial community. In 1909 the Census Bureau reported that 16 different industries in the city had each an annual output valued at over a million dollars. Many of these industries, and particularly the Winchester Repeating

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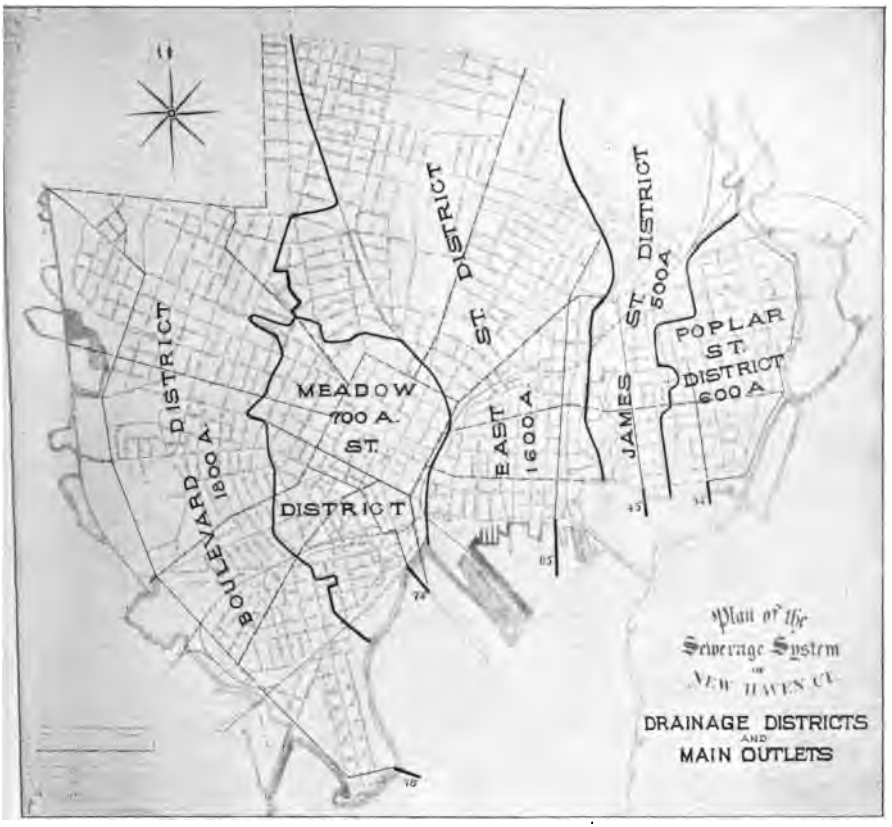

Fig. 1.

SEWERAGE SYSTEM OF NEW HAVEN. BOUNDARIES BETWEEN AREAS TRIBUTARY TO EACH OF THE FIVE OUTFALLS INDICATED BY HEAVY LINES

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Arms Company, have grown very rapidly during the past four years. It is to be expected therefore that the sewage of the city will contain a considerable proportion of industrial wastes, particularly of such wastes as are derived from machine shop processes. The industrial wastes, aside from the private sewers mentioned above, are however largely confined to the East Street sewer, the discharge of the other four main outfalls being mainly domestic sewage. The Sea Street sewer has recently received considerable contributions of dye liquor, but these while they affect the appearance of the sewage discharged do not materially complicate the problem of disposal. According to Mr. Harrub, nearly a third of the total discharge of the East Street sewer is made up of industrial wastes, among which are 3,500,000 gallons of acid waste from arms and hardware manufacturing plants, 300,000 gallons of dairy waste and 80,000 gallons of rubber washings per day.

RESULTS OF THE DISCHARGE OF SEWAGE INTO NEW HAVEN HARBOR

A large part of New Haven Harbor is shallow, particularly in the vicinity of the Sea Street outfall. There is a central dredged channel 20 feet deep; but outside of this the inner harbor (above a line drawn from Fort Hale to Sandy Point) will not average five feet in depth. The outfalls are all above low water mark and the sewage, as it spreads over the flats and deposits sludge upon them, produces at times a condition of gross nuisance; while the presence of the untreated sewage constitutes a possible menace to the health of those who bathe in the harbor or consume shellfish grown therein.

In the year 1910 J. A. Newlands and G. C. Ham made a somewhat extensive study of the condition of the New Haven harbor waters in connection with the possible pollution of the oyster grounds, over a thousand samples of water and oysters being examined. The average bacterial counts of 47 samples of water ranged between 120 and 2650 per c. c. (cubic centimeter) (at 20°C). Seventeen of the stations showed averages of over 1000 and one station (at Tomlinson Bridge) averaged 2650. Twenty-three of the stations in the upper harbor showed average counts of *B. coli* (the common type of intestinal bacteria) ranging between 4 and 74 per c.c. (twelve stations under 10, five between 10 and 20, six over 20). Of the twenty-

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three stations further down the harbor, four showed averages of between 1 and 5 *B. coli* per c.c. and nineteen showed less than 1 per c.c.

In 1915 the United States Bureau of Chemistry made a study of the sanitary condition of the harbor, which led to the conclusion that its waters were so polluted that no oysters for sale in interstate commerce should be grown "in the area marked by a line connecting Morgan Point on the east with Oyster River Point on the west and passing through the breakwater;" unless such oysters were purified by transplanting them in non-polluted waters for at least seven days before shipment. Analyses furnished by the Bureau to the City Department of Health, and courteously made available for our use by Dr. F. W. Wright, show that of sixty-two samples of water from the Upper Harbor (above a line from Sandy Point to Fort Hale) fifteen contained over 100 *B.coli* per c.c., twenty-six between 10 and 100, fourteen between 1 and 10, and seven less than 1 per c.c. Of thirty-seven samples from the outer harbor, one showed over 100 *B.coli* per c.c., ten between 10 and 100, nine between 1 and 10, and 17 less than 1 per c.c. The average for the upper harbor was twenty-nine per c.c. and for the lower harbor, about three per c.c.

During the summer of 1916 a corps of experts from the United States Public Health Service, under the direction of Dr. H. S. Cumming, conducted another exhaustive survey of the harbor waters. Float tests made in the course of this investigation showed that fresh sewage reaches all parts of the harbor during the period of a single tide. "Floats set out at the mouth of the East Street sewer traversed the entire length of the harbor to the breakwater in one tide, while those set out at the Sea Street outfall went out to the mouth of the harbor or up West River, according to the direction of the tide. One float started at the mouth of the Sea Street outlet, went down the harbor to the vicinity of Old Tower, and then turning in a westerly direction went the entire distance across the harbor to the cove at Cox's Beach in a period of eight hours. One float started at the mouth of the Poplar Street sewer outlet at the beginning of a flood tide,, travelled about six or seven miles up the Quinnipiac River on the flood tide and back to its starting place on the following ebb tide. On several occasions it was possible to trace a coutinuous line of

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fresh feces floating from the Sea Street outfall across the harbor into and through Morris Cove and down to Old Tower." (C. N. Harrub).

The result of analyses of the harbor waters at this period, courteously furnished to us by Dr. H. S. Cumming, are considerably higher than those given in either of the previous reports. A large proportion of the samples in the Newlands and the Bureau of Chemistry studies were taken in the immediate vicinity of oyster layings, while the Public Health Service samples were so collected as to furnish a very fair picture of general harbor conditions. This may in part account for the higher results obtained; but there is also no doubt a progressive increase in the extent of the pollution from year to year. A cross section of the harbor just below the East Street outfall gave an average of 238 *B. coli* per c. c., a section below the Meadow and State Street outfalls an average of 330 per c.c.; a section below the Sea Street outfall an average of 246 per c. c.; a section from Sandy Point to Fort Hale, an average of 158 per c. c.; a section from Old Field Creek to Morris Cove an average of 120 per c. c.; and a section from Cove River to Old Tower Point an average of 23 per c. c.

Dissolved oxygen values for surface samples on these six sections averaged as follows:

	Dissolved oxygen Per cent saturation
Section 1	70.0
Section 2	80.5
Section 3	77.5
Section 4	86.0
Section 5	94.0
Section 6	81.0

As a result of this investigation Dr. Cumming made the following report to Dr. F. W. Wright, Health Officer of the City of New Haven:

"The investigation included:

"1. Observation of the origin and character of the discharge from the various sewer outfalls.

"2. Observation of floats set near the outfalls and of feces and other floating matter discharged therefrom, with reference to the direction and distance traveled by them over various periods of time and tide.

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"3. Laboratory examinations of approximately one thousand eight hundred samples of mud, water and shellfish taken from all parts of the harbor.

"As a result of the investigations so far made, the following conclusions have been reached:

"1. That the harbor of New Haven, and the tidal portions of the Quinnipiac, West and Mill Rivers above the line between Bradley Point and Old Tower are grossly polluted by sewage discharged from the sewer outfalls in the harbor.

"2. That the portion of the harbor which lies below the above line, and within the breakwater contains a smaller proportion of pollution because of the dilution at each incoming tide and the sedimentation of some of the sewage before it reaches the area.

"3. All of the first described area, and probably all of the second, certainly that portion adjacent to the channel, receives sewage, including human feces, within one tide, or about six hours after its discharge from the sewer outfalls. The sewerage system of New Haven is so constructed that sewage is discharged unusually fresh and before disintegration has taken place.

"4. The direction of flow and distance traveled by the sewage from any outfall is determined by the combined action of the tide and wind.

"5. Shellfish in the harbor are exposed to pollution by sewage from the city and are filthy, dangerous and unfit to be eaten as taken from the area.

"Owing to their greater physiological activity during warm weather, the danger of conveying infectious pollution is greatest during such periods, and the eating of uncooked shellfish taken from along the fore shore and in the immediate vicinity of sewer outfalls is particularly dangerous to health.

"There is no sanitary reason why shellfish should not be grown in the harbor if they be transferred to unpolluted waters for a period of about ten days before they are taken for food.

"6. Bathing and swimming in the waters of the harbor above the line between Old Tower and Bradley Point, and in the rivers is unsafe and should be prohibited. The practice, which

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seems common, of bathing in the rivers and along the fore shores in the vicinity of sewer outfalls is especially dangerous.

"The dike at Sandy Point diverts grossly polluted waters from the sewer outfalls above that point, toward and into Morris Cove; floats and pieces of feces have been followed from the outfalls to the bathing beaches at Fort Hale and in Morris Cove, including the vicinity of the Yacht Club.

"The sewage along the shore from Savin Rock to Bradley Point comes in part from the sewer outfall of the West Haven Disposal Plant, though it is probable that some of it comes from the city sewer outfalls as has been shown by the floats which traveled from the City Point outfall to Cox's Beach within eight hours.

"Briefly, I recommend that the taking of shellfish from the harbor of New Haven be prohibited, except under such precautions as will insure that they will not be used as food until after purification.

"That the bathing in the grossly polluted, filthy waters of the harbor and rivers be prohibited.

"That the city continue to take such appropriate steps as will eventually insure the proper disposal of its sewage."

HISTORY OF THE PRESENT INVESTIGATION

In the spring of 1916 it became clear to the officials of the city of New Haven that some steps must be taken to ameliorate the serious conditions arising from the present method of sewage disposal. On April 19th Mayor Frank J. Rice appointed a Citizens' Committee "to cooperate with the Aldermanic Committee on Sewers and Sanitation in recommending changes in the sewage disposal of the city of New Haven." The joint Citizens' and Aldermanic Committee thus formed directed the Committee which makes the present report to conduct an investigation of the best practical processes for the treatment of the sewage of the city with a view to remedying the conditions which exist at the present time. A preliminary appropriation of $500 for preparing the plans of such a study was made in June and in the fall an appropriation of $15,000 was requested for the actual conduct of experiments. In response to this request the sum of $11,000 was included in the city appropriations for 1917. Work was at

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Fig. II.

VIEW OF THE EXPERIMENTAL PLANT, LOOKING EAST. FROM LEFT TO RIGHT, IMHOFF TANK, PUMP HOUSE, ACTIVATED SLUDGE TANK, MILES ACID TANK.

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once begun on construction and the Experiment Station was completed and in continuous operation by June 2, 1917. It became clear in the fall of 1917 that the sum of $11,000 provided would prove insufficient even to complete the work of the calendar year, and that in order to carry the experiments to a successful conclusion they must be continued into the year 1918. A deficiency appropriation of $3,626 was therefore made for the balance of 1917 and the sum of $4,250 allotted for 1918, a total appropriation of $18,876. The cost of the experiments, which were completed May 1, 1918, was as indicated below:

Cost of construction and equipment.....	$8,923.40
Cost of operation	9,584.46
Total gross cost	18,507.86
Return from sale of apparatus and material..	588.60
Total net cost	$17,919.26

It may be noted that all the members of the Committee directing these experiments gave their services without charge to the city. Sargent & Company furnished the land occupied by the Experiment Station rent free.

The Committee desires to express its appreciation of the constant helpfulness and the many courtesies received from Mr. F. L. Ford, City Engineer, and Mr. H. J. Kellogg, Engineer in charge of the Sewer Division. Mr. H. J. Wynne of this Division was assigned to assist in the experiments during the spring of 1918 and was of the greatest assistance in the completion of the work. Mr. T. C. Hillhouse, assistant to Mr. Kellogg, made a valuable series of gauging observations at the sewer outfalls in the summer of 1916. The thanks of the city are also due to the chemists and other officials of the Cobwell Company and Colgate and Company of New York, The Tolhurst Company of Troy, N. Y., William M. Ware and Company of Boston, the Falk Company of Pittsburgh, and Armour and Company and Swift and Company of Chicago, who assisted materially in the estimation of the value of grease and other products to be recovered from the sewage.

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Dr. F. W. Mohlman acted as chemist in charge of the plant and Mr. W. S. Sturges, Jr., as bacteriologist during the whole period of operation.

SCOPE AND PLAN OF THE INVESTIGATION

No attempt has been made in the present investigation to pass upon the broad question of the possibility of collecting the sewage of New Haven by a system of intercepting sewers and transporting it to some single remote point. Nor has the question of a possible combination of the city and its surrounding towns into a Metropolitan District for joint sewerage and sewage disposal been considered. The Committee has accepted the opinion of engineers, who have given previous study to the problem, that intercepting sewers, with the cost of pumping necessarily involved, would be unduly expensive. It has been therefore assumed that the sewage from the areas at present discharging into the main sewers would be disposed of approximately at the present points of discharge, with a probability that the flow from the Poplar and James Street sewers could perhaps profitably be combined.

This assumption of four relatively small disposal plants located in thickly settled districts near the head of New Haven harbor makes any consideration of treatment on bacterial beds quite out of the question. Furthermore it seems clear from such studies as have been made of the diluting capacity of the harbor that if a reasonable proportion of the suspended solids were removed and the liquid constituents of the sewage properly diffused, no general exhaustion of the dissolved oxygen content of the harbor need be anticipated. The tidal prism of the whole harbor is estimated by Mr. H. J. Kellogg to be 300 times the sewage flow.

On the other hand we believe that in order to avoid nuisance from the presence of sewage on the flats it will be essential to extend the outfall sewers to submerged outlets in the main channels. The mere digging of lateral channels, as has been done at the Sea Street outfall, from shore outfalls to the main channel must prove inadequate as the experience at Sea Street during the past summer has already shown.

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While the discharge of the sewage through submerged outlets into the main channel itself will relieve conditions along the fore shores it will by itself tend to increase rather than to diminish the menace to bathing beaches and shellfish areas which the sewage will reach even more promptly than is the case at present. Furthermore the construction of such outlets will deposit sludge in the channels themselves instead of on the flats and might cause harmful silting if the untreated sewage were thus discharged.

For these reasons we believe that any plans for the disposal of New Haven sewage should provide for (a) a substantial removal of suspended solid matter and (b) substantial bacterial purification. Disinfection of the sewage is absolutely essential during the bathing season. In the winter it might be avoided if the harbor were permanently closed for the taking of shellfish or if all shellfish from the harbor were submitted to a subsequent process of purification. We have assumed in our calculations that a reasonable degree of bacterial purity would be required at all times; but the relative costs of the various processes, with disinfection limited to a specified period, can be easily computed from the data given.

These preliminary considerations led us to limit our study to four processes of sewage treatment, fine screening followed by disinfection, Imhoff tank treatment followed by disinfection, Miles acid treatment, and activated sludge treatment. These are the only four processes which could in our judgment reasonably be considered as meeting the conditions of the problem—conditions calling for compact plants which will yield clarified and bacterially purified effluents.

We have planned our experiments so as to determine what results might be expected, and at what cost, from the treatment of the East Street sewage by each of these four processes. The East Street sewer was chosen not merely as the largest but chiefly because the peculiar composition of the sewage, due to its contained industrial wastes, made its behavior more uncertain. In addition to the main studies at East Street we have also tested out fine screening and Miles acid treatment with the sewage of the Boulevard sewer, the chief artery of the Sea Street system, which is a typical domestic sewage. It seemed unnecessary to experiment with the Imhoff tank and activated sludge

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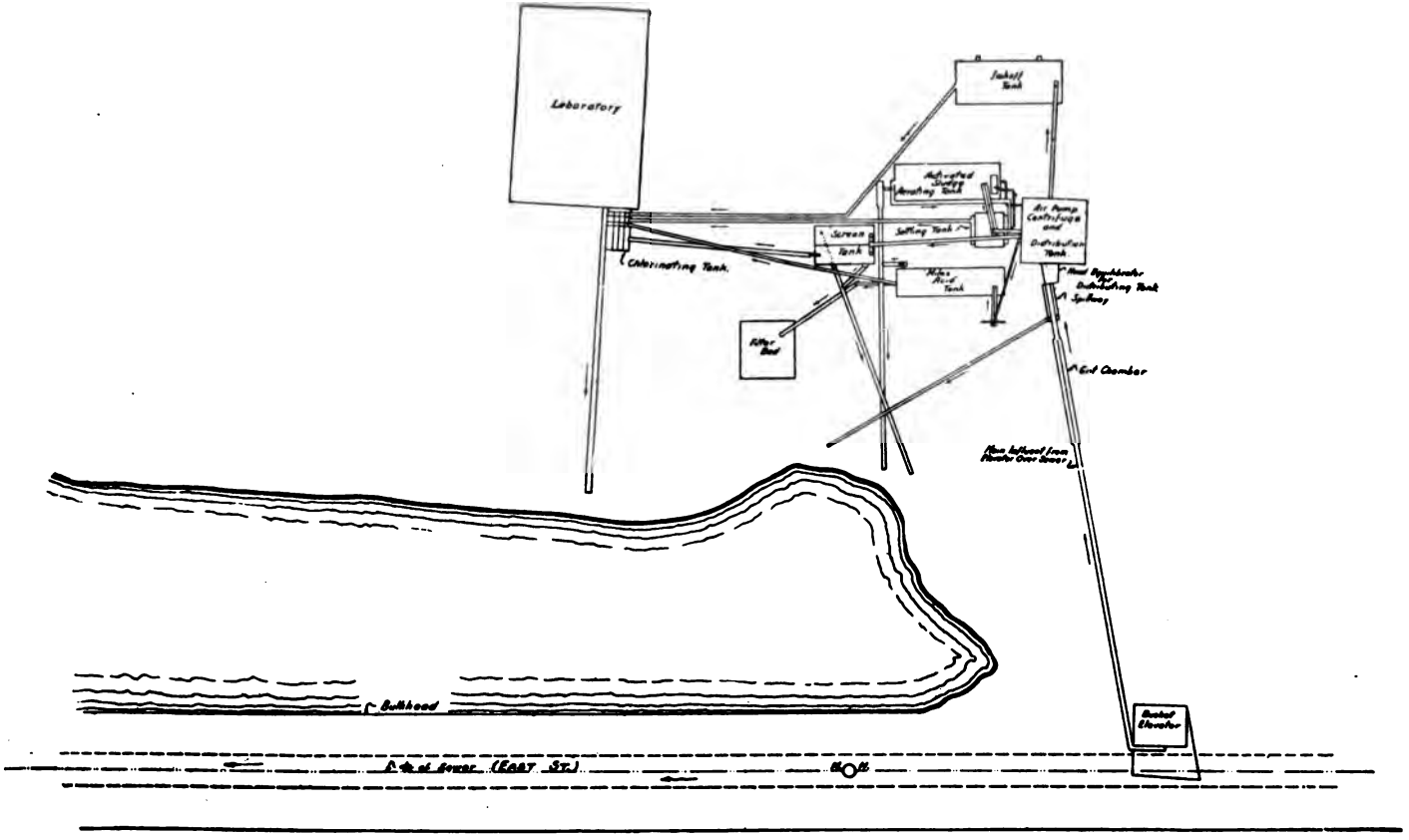

Fig. III.
GENERAL PLAN OF EXPERIMENTAL PLANT AT EAST STREET.

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at this latter point, since the results to be obtained from these processes with normal house sewage are fairly well understood. We have been able to arrive at a definite conclusion as to the next step to be taken in solving the complex sewage disposal problem of the city—the construction of a disposal plant at the East Street outfall—and we suggest alternative plans for other plants, the choice between them to be made after the actual operating results of the East Street plant are available for comparison.

Ultimately it will be necessary to provide for treatment, not only of the discharge from the present five main outfalls, but also of the five million gallons now discharged from private sewers at various points. Local conditions however make the adequate treatment of the sewage of the city a peculiarly difficult engineering problem and one that can only be solved one step at a time.

DESCRIPTION OF THE EXPERIMENT STATION AND ITS GENERAL OPERATION

The details of the Sewage Experiment Station were designed by Mr. R. H. Skelton with the advice and supervision of Professor S. E. Barney of the Sheffield Scientific School. The general arrangement of the Station is indicated in Figure III and views of various portions of it are shown in Figures II, VI and IX.

Bucket Elevator. In most stations with which we are familiar the sewage for experimental purposes has been withdrawn from the sewer by pumping. Such a procedure is unsatisfactory, however, particularly for studies which include screening, since it is difficult to obtain a fair and normal representation of the actual sewage flow by the use of a small pump. The surface solids containing floating material and grease are not fairly represented and the suspended matter is broken up so as to make screening investigations unreliable. It was finally concluded that a bucket elevator would be the most satisfactory form of apparatus for obtaining a representative and unaltered sewage for experimental purposes.

An elevator such as we desired could not be purchased ready made, but the various parts were finally obtained from several

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Fig. IV.

VIEW OF THE BUCKET ELEVATOR.

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manufacturers and the structure assembled as shown in Fig. IV. In order to form a proper base for the elevator, the invert of the sewer was extended out to one side, in the form of a flat slab of reinforced concrete 12 inches thick, 6 feet wide and 10 feet long . This slab rested on the piles which supported the sewer. A masonry wall was built up around the edge of this slab, forming a water-tight forebay at one side of the sewer. The elevator was erected in this forebay, and after the elevator was complete two openings were cut from the forebay into the side of the sewer. These openings were each three feet wide and extended down to the invert of the sewer. A galvanized iron deflector built out from the lower side of the upper opening nearly to the center line of the sewer deflected a large fraction of the sewage flow into the forebay through the upstream opening, the sewage passing out of the forebay back into the sewer through the lower opening. The level of the sewage in the forebay, like that in the sewer itself, would rise and fall with the tide, but the composition of the sewage was not materially changed.

The elevator was built on a heavy frame of 6″ x 8″ timbers 8 feet long by 5 feet wide. The design of the elevator is shown in Fig. V. The chains were in parallel, with the buckets fastened to them at every sixth link. The chains passed over two sets of sprocket wheels at the top and one set at the bottom. The larger sprocket wheel at the top, 24 inches in diameter, with 19 teeth, was on the same shaft with a large 60-inch gear with 125 teeth, which in turn was driven by a pinion 6 inches in diameter, with 12 teeth. The pinion was mounted on the same shaft with a pulley 38 inches in diameter, with 4 inch face, which was belt-driven from a 5-horse-power motor with a 4 inch pulley. The motor ran at 1730 revolutions per minute, the pinion at 182, the large gear at 17.4. As a bucket was fastened to each sixth link, and the drive sprocket had 19 teeth and ran at a rate of 17.4 r.p.m., the number of buckets discharging per minute was 55. There were in all 18 buckets on the chain. Each bucket had a total capacity of 2.64 gallons, but by the time the sewage was discharged 20 per cent had been lost by splashing, so that 55x2.64x.80=116 gallons per minute or 167,000 gallons per day represents the amount actually delivered by the elevator. The buckets were submerged to within 3 inches of the bottom of the forebay, and rose vertically through the current of sewage. The bottom of the forebay was at elevation

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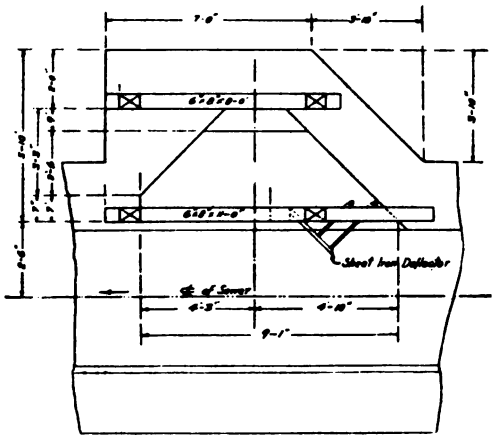

FIG. 1.— PLAN

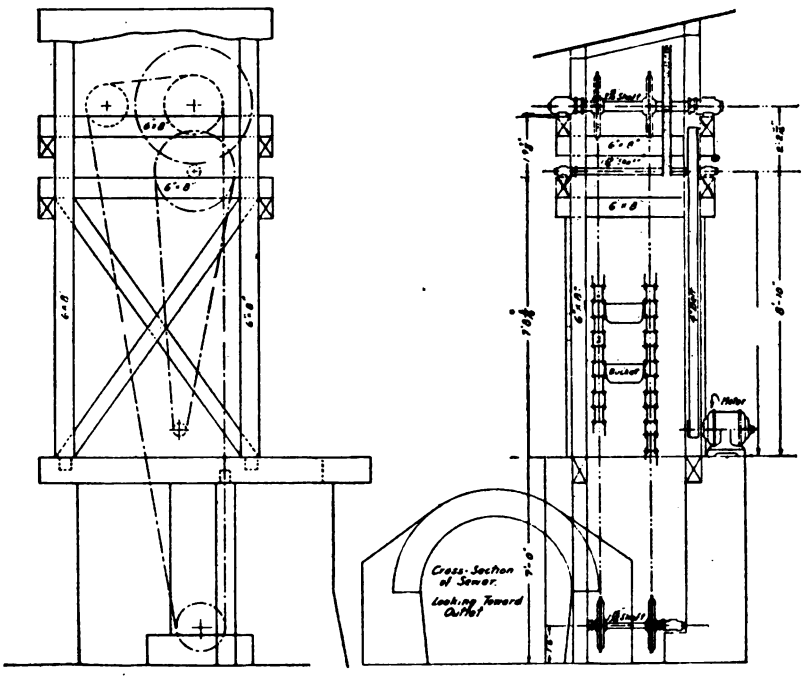

FIG. 2 — SIDE

FIG 3—END

Fig. V.

DESIGN OF BUCKET ELEVATOR.

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-3.6 and the buckets discharged at elevation +13.9, giving a lift of 17.5 feet. The buckets discharged the sewage into a galvanized iron hopper suspended between the two upper sprocket shafts. From this hopper the sewage flowed by a wooden flume to the plant.

On the whole the operation of the bucket elevator proved very satisfactory. Some difficulty was experienced when stones lodged under the buckets and knocked the chains off the lower sprockets; and during the first severe cold weather the spray froze solidly around the upper part of the structure, putting the apparatus out of commission for several days. After this the entire structure was boarded up, and the warmth of the sewage proved sufficient to prevent freezing. A great deal of trouble was caused by wet belts, but as it was impossible to avoid this difficulty without changing the location of the motor and lengthening the shafting, new belts were used as soon as the previous ones had been weakened by moisture. The sewage was not churned violently by this apparatus and a very representative sample was obtained. Oil, paper and feces were brought up and dicharged in about the same condition and amount as in the flowing sewage. The cost of operating this elevator was much greater than the cost of operating a centrifugal pump would have been, but since the work was experimental, it was considered that a representative sample of sewage was more essential than economical operation.

Grit Chamber. The sewage flowed from the top of the elevator to the station through a wooden flume six inches wide by six inches deep, with a slope of 1 to 100. Before reaching the distribution box it passed through a grit chamber. This grit chamber had two compartments, which could be used alternately. Each compartment was 15 feet long, 12 inches deep at the inlet end, 4 inches deep at the outlet end, and 4 inches wide, which gave a detention period of 0.24 minute. The velocity of the sewage was checked to 0.7 foot per second at the inlet end, increasing to 2.1 feet per second at the outlet end. When much storm water was mixed with the sanitary sewage this grit chamber proved inadequate, so that supplementary grit chambers were installed for the sewage delivered to the activated sludge and Miles acid tanks. Our experience with this first grit chamber proved that where the combined system of sewerage is in use it is very essential to have reserve grit chambers which can be used when storm water sewage

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is being treated. Unless ample grit chamber space is available the settling basins will receive a great deal of inert mineral matter, which will lower the value of the sludge in processes where sludge recovery is an essential step.

Weir Box. The usual method of measuring the sewage used in experimental work is by means of orifices. In our experiments it was obvious that this method would not be satisfactory since large particles of suspended solids would quickly clog the small orifices necessary, and, if constant head were maintained by an overflow, the floating matter would be carried over the waste weir and would not be drawn into the currents of sewage passing through the submerged orifices. Movable weirs were therefore used instead of orifices, and, after the weirs were adjusted to the quantity of sewage required for each process, a constant head of sewage was maintained over them by an automatic head-regulating device. Since some experiments required as little as 10,000 gallons per day or 7 gallons per minute, we used for these processes 60° V-notch weirs, so as to obtain a greater width of crest for a given discharge than could be obtained with a rectangular weir. This was desirable, in order that the weir might not be frequently clogged by paper or feces.

The head regulating device consisted of a float in the weir box, with a vertical spindle at its center which operated a needle valve. This needle valve controlled the flow of city water to a small brass cylinder, in which was a piston which opened and closed a butterfly-valve in the raw sewage flume. As the level of sewage dropped in the weir box the butterfly-valve was opened by the piston, and as the level increased the valve was closed. After proper adjustment, and with some attention, this apparatus, constructed by Wallace and Tiernan of New York, maintained the head of sewage in the weir box constant within one-sixteenth of an inch.

The weir box was 27 inches square by 8 inches deep. The weirs were all attached to a weir plate at one end of the box. Three 60° V-notch weirs were used for the Imhoff, activated sludge and Miles acid processes, and one rectangular weir, 7½ inches wide, for the screening influent. All weirs were calibrated by volumetric tests.

Screen Studies. Screening experiments were planned with the expectation that an experimental Riensch-Wurl screen would be

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furnished by the Sanitation Corporation of New York City, but when the time came for the installation of the screen, the Company wrote that it was not in working order, and that they could not repair it so that we could use it. As there was great difference of opinion among sanitary engineers as to the efficiency of fine screens we felt that it was essential to obtain some data upon this process. In view of the specially favorable conditions for screening experiments provided by the installation of the bucket elevator, we therefore decided to conduct our experimental work along this line with hand-operated stationary screens. Two screens of 30-mesh monel-metal wire cloth were constructed, with a back support of half-inch galvanized iron wire netting. The screens were made of wire, .01225 inch in diameter, the open space being 40 per cent of the total area. Other screens were constructed of rolled sheets of galvanized iron ⅛ inch thick, perforated with slots 1¼ inches long and 1/16 inch wide, punched in the plate at intervals of 3/16 inch laterally and ½ inch horizontally. The plates were galvanized after the holes were punched, so that the area of the openings was slightly reduced by the zinc with which the sides of the openings were coated. The perforations made up 21 per cent of the total area of the plate. They were not exactly similar to the Riensch-Wurl perforations, since the lower sides of the slots were not beveled and the corners were not rounded, but it is not probable that these minor differences are of great significance.

The screens, which were all two feet wide by 3 feet long, were placed on cleats in a screen chamber 8 feet 10 inches long by 2 feet 6 inches wide and 2 feet 6 inches deep. The cleats were faced with rubber strips so that a tight joint was made with the frame which held the screens, the screens resting on the cleats at an angle of 45°. Sewage was passed through them at the rate of 100,000 gallons per day. As the screen clogged the sewage gradually built up behind it and in from 15 minutes to half an hour, when the loss of head reached two feet, a second screen of the same type was placed in the chamber, resting on cleats two feet below those on which the first screen was placed After the second screen was in position, the first one was pulled out of the chamber, and allowed to drain. The second screen was allowed to remain in position until the loss of head had again reached 2 feet, when the sewage was by-passed, and the sewage remaining in the screen chamber removed by opening vents in the side of the tank. After the sewage had been drawn

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down to within half an inch of the bottom of the tank the second screen was removed and drained. The amount of sewage passed through the two screens in each experiment averaged about 3000 gallons.

After draining, the screenings were brushed off the screen, weighed, and the moisture content determined. The effluent was sampled frequently during screening and the suspended solids in the composite sample determined. Knowing the quantity of sewage screened and the weight of the dry screenings, the parts per million of suspended solids removed, and the per cent removal could be calculated. This method of determining removal of suspended solids is more reliable than that in which determinations of suspended solids are made on samples of sewage collected before and after screening, since the coarser suspended matter, such as feces, fruit skins and paper are usually not collected in the sample of raw sewage, and thus the screen is not credited with the removal of material which it does actually retain.

Such a study of screening by the use of stationary screens is open to criticism on the ground that it permits a much greater clogging than would occur in practice with a revolving screen cleaned automatically during the process. The clogged screen will, of course effect a greater purification than one that is kept clean. If the head were allowed to increase beyond a certain point the pressure would operate in the opposite sense by forcing an undue proportion of solid matter through the meshes. With a loss of head never rising above 2 feet this criticism cannot be made, since this is a range within which commercial screens are supposed to operate. Our method of experimentation was therefore exceedingly favorable to fine screening; and since even so the results obtained were poor we may be sure we were on the safe side. and that results in practice would be even less satisfactory. At Cleveland small stationary screens showed a removal of 25 to 28 per cent of suspended solids, while an actual Riensch-Wurl installation (operating; it is true, on the sewage of a different district) only removed 2 to 5 per cent. Another circumstance which was specially favorable to screening in our experiments was the fact that the tests were always made in the day time with the strongest sewage of the twenty-four hours.

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Fig. VI.

VIEW OF IMHOFF TANK WITH LABORATORY BEYOND AND OUTFALL SEWER IN THE DISTANCE

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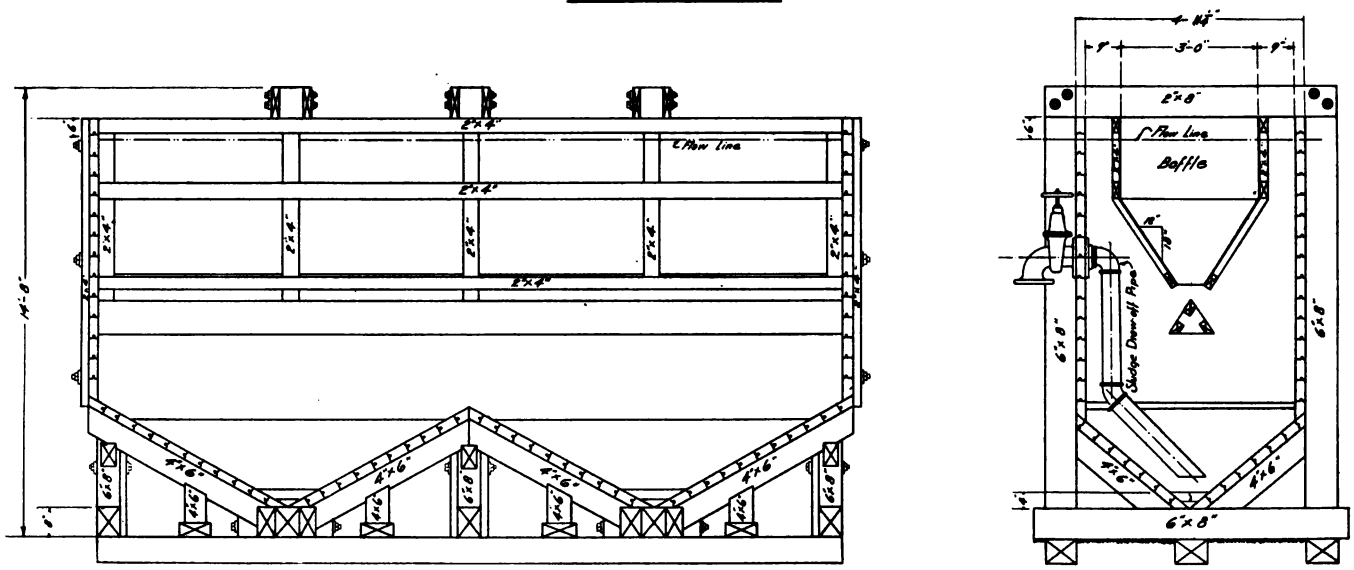

LONGITUDINAL SECTION

CROSS SECTION

Fig. VII.

PLAN AND SECTION OF IMHOFF TANK.

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Imhoff Tank. The Imhoff tank (Fig. VII) was constructed of tongue-and-groove spruce, with calked seams. It was rectangular, 16 feet long by 4 feet 6 inches wide, by 11 feet 6 inches deep. The flow chamber extended the full length of the tank with gas vents 8 inches wide on each side. The flow chamber was constructed of heavy galvanized iron, as shown in the plate, with a triangular beam below the vent. The vent was eight inches wide, and the seal overlapped each side two inches. The sides of the flow chamber sloped at 60° so that no difficulty was encountered from solid matters clinging to the slope. The capacity of the flow chamber was 840 gallons. The detention period was theoretically 2 hours when treating 10,000 gallons of sewage per day. The linear velocity of the sewage was .15 foot per minute.

The sludge compartment as designed was out of proportion to the flow chamber, being relatively much larger than would be designed for a full-size plant. It was assumed that a large sludge compartment might be needed on account of the shallowness of the tank. The bottom of the tank was built in the form of two inverted pyramids with the sludge draw-off pipes just above the apices. When the tank was first filled with sewage the pressure forced the bottom planks toward the sides and the sewage ran out of the tank as fast as it ran in, the porous ground allowing it to escape into the slip alongside of the sewer outfall. The tank was cleaned seven times in the effort to stop the leaks, and various methods of making it tight were attempted. Success was finally attained by placing extra heavy timbers under the bottom planks, by nailing one layer of canvas and three of tar paper over the inner surface of the sludge compartment, each layer being thoroughly coated with pitch, and finally by running three-quarter inch tie-rods through the tank, one on the short axis and two similar rods on the long axis. After this it held water fairly well and was placed in operation in November 1917. On account of the delay, however, only six months' operation of the Imhoff tank was possible.

Activated Sludge Tanks. Our activated sludge experiments were made on the continuous-flow basis. The aerating tank (Fig VIII) was 16 feet long, 4 feet wide and 8 feet deep. At the bottom of the tank the sides sloped at 45° to a trough 1 foot wide, running the full length of the tank. An iron frame in which were cemented

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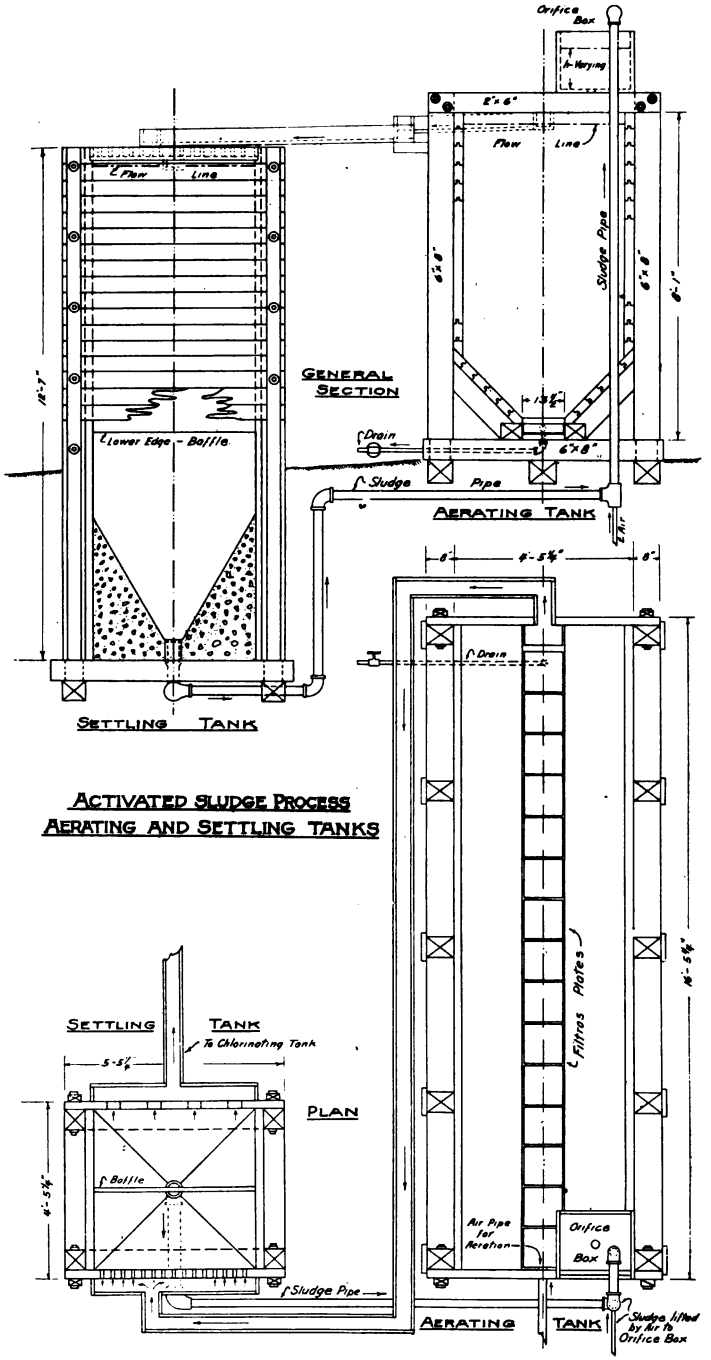

Fig. VIII.

PLAN AND SECTION OF ACTIVATED SLUDGE AERATING AND SETTLING TANKS.

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15 filtros plates was cemented into this trough. The air was admitted at the inlet end of the trough, and the water which filtered through the plates could be drawn off at the outlet end. The air was compressed to 3.5 lbs. pressure by a Nash Hydro-turbine having a capacity of 20 cu. ft. of free air per minute, the flow being measured by means of a Venturi tube.

The settling tank was 4 ft. x 4 ft. in plan, and 12 feet deep to the bottom of the hopper. This hopper sloped at 60° to a sump in which was cemented a 3-inch ell connected to the suction of an air-lift pump. The sludge deposited here could be pumped back to the aerating tank, being measured on the way in an orifice box. A baffle 7½ feet deep extended across the center of the settling tank. This baffle was first placed 3 feet from the inlet weir and 1 foot from the outlet weir, but the upward velocity of the effluent was too strong and carried particles of sludge over the outlet weir. After placing the baffle in the center of the tank no sludge was lost in this way, the theoretical upward velocity being decreased by this change from 4.8 in. to 2.4 in. per min. The capacity of the aerating tank was 3100 gallons, that of the settling tank 1150 gallons. While treating 17,000 gallons of sewage per day with 50 per cent returned sludge the aeration period was 3 hours, the settling period 66 minutes.

Chlorination. The effluents from the screen chamber, the Imhoff tank and the activated sludge process were conducted by wooden flumes to small baffled tanks giving detention periods of from 2 to 5 minutes, where they were chlorinated. The chlorine was applied in the form of liquid chlorine delivered from a Wallace and Tiernan solution-feed apparatus, designed for these experiments, with three solution jars and volumetric meters. The chlorinated samples were held in the sample bottles for 30 minutes before plating, to reproduce the action of the small storage tanks that would be required in an operating plant.

Miles Acid Treatment Process. . The tank used for sedimentation of sewage after treatment with acid was a wooden tank 16 feet long by 3 feet 6 inches wide and 4 feet deep, having a capacity of 1680 gallons. When treating 10,000 gallons a day, the average detention period was therefore 4 hours and the linear velocity through the tank was .066 foot per minute. During the first ex-

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Fig. IX.

VIEW OF PORTION OF EXPERIMENTAL PLANT, LOOKING NORTH. FROM LEFT TO RIGHT IMHOFF TANK, ACTIVATED SLUDGE TANK, PUMP HOUSE, MILES ACID TANK.

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periments made with this process the sewage entering the tank was treated with SO_2 gas generated by a sulphur burner, which is the method that would no doubt be adopted in practical installations. On a small scale however this process proved very difficult to control and for the bulk of our studies we used liquid sulphur dioxide as prepared in cylinders for commercial use, (a process far too costly for practical use in sewage treatment). The gas was delivered through a rubber tube into the sewage as it flowed from the weir box to the tank through a 2-inch galvanized iron pipe 18 feet long. The amount of gas was controlled by noting each half hour the loss of weight of the SO_2 cylinder which rested on a platform scale.

Experimental Plant at the Boulevard Sewer. In view of the very peculiar characteristics of the East Street sewage it seemed important to obtain data in regard to the treatment of a more normal New Haven sewage by at least two of the processes studied, screening and Miles acid treatment. The Boulevard sewer, which is the main trunk sewer of the system discharging at Sea Street, was selected for this purpose; and we were fortunate enough to find a location where this sewer passed through an embankment above the level of an adjoining marsh. It was found possible to draw off from the sewage flow a sufficient amount for experimental purposes by the use of a 3-inch galvanized iron siphon (provided with quick-closing valves at either end) with its shorter leg extending down into the sewer through a manhole. The longer leg of the siphon dipped into a stilling box 3 feet square and 3 feet deep provided with an overflow weir to maintain a constant head. From this stilling box the sewage for experimental purposes passed to the tank used for screening or Miles treatment over a rectangular weir in the former and a triangular notch weir in the latter case.

For the experiments themselves we moved the wooden tank, (Fig. X), used in the screening experiments at East Street, to a point on the marsh adjoining the stilling box, and the sulphur dosing apparatus was housed in a small frame building erected for the purpose.

The tank in its original form was 8 feet 10 inches long, 5 feet wide and 2 feet 6 inches deep and was divided into the two longitudinal compartments used for the screening experiments. It was at first set up at the Boulevard sewer without structural change and a

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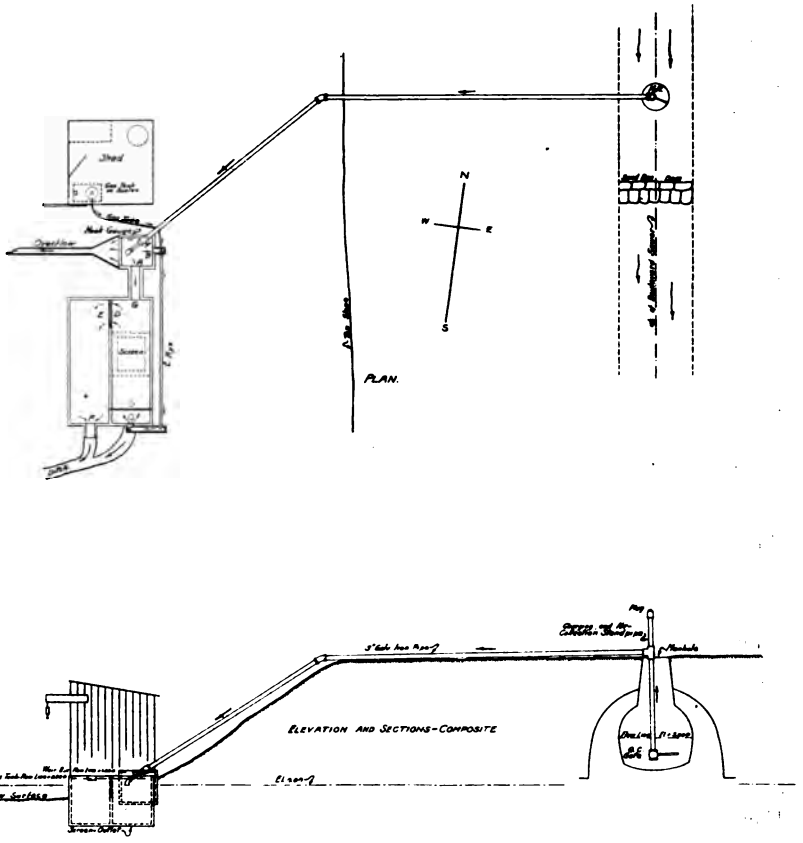

Fig. X.

PLAN AND SECTION OF EXPERIMENTAL PLANT ON BOULEVARD SEWER.

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few tests were made of the process of fine screening. The upper foot of one end of the longitudinal partition was then removed and, for the Miles acid studies, the sewage was allowed to flow down one side of the tank and back the other, giving approximately the effect of a tank about 16 feet long and 2.5 feet wide.

Sampling Schedule and Analytical Methods. Routine samples of sewage and effluents were collected for chemical analyses every hour and mixed and analyzed daily. Samples for bacteriological examination were collected twice daily, at 8 a. m. and at 11 a. m. In all 1048 chemical samples of sewage, effluents and sludge and 1074 bacteriological samples were examined. Only monthly averages and special averages for individual experiments are presented in this report, since individual analyses have no special significance; but the original data have been filed for reference in the office of the City Engineer of New Haven.

Chemical examinations were made in all cases, unless otherwise specified, in accordance with the procedure laid down by the Committee on Standard Methods of the Laboratory Section of the American Public Health Association. The number of bacteria was determined by plating on agar and incubating for 3 days at 20°C. The reason for adopting the three day period will be discussed in the succeeding section. The number of organisms of the colon group was determined by the fermentation test in lactose broth incubated for 2 days at 37°C.

COMPOSITION OF THE RAW SEWAGE

As before noted, New Haven is sewered on the combined plan and since practically all of the section of the city drained by the East Street sewer is paved, the run-off in this sewer following a storm is very great. The sewage at such times is highly diluted and very muddy. Aside from this character of high dilution the sewage is distinctly abnormal in other respects, as we discovered at the very outset of our investigations.

Chlorine Content of the Sewage. On May 7-8, 1917, a series of hourly samples of raw sewage were collected and analyzed in order to determine the fluctuations in quality of the sewage throughout the twenty-four hours. The results of this test are shown in Table II.

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TABLE II. Analyses of Samples of Raw Sewage Collected at Hourly Intervals. May 7-8, 1917.

Time.	Parts per Million									
			Nitrogen				Solids			
	Chlorine	Alkalinity	As NH_3	Total Organic	NO_2+NO_3	O Consumed	Suspended	Total	Bacteria per c. c. 20°C	Gas Formers per c. c. 37°C
8 a. m.....	2075	76	10.4	17.6	3.8	50	165	4430	4,200	100
9 "	2750	94	7.6	14.0	2.6	49	445	6178	....	....
10 "	2725	70	6.0	11.0	2.4	50	230	5880	4,500	100
11 "	2875	90	4.0	13.6	2.4	50	122	5057	....	....
12 "	2775	104	4.2	12.6	2.5	51	133	5872	70,000	1,000
1 p. m.....	2675	98	4.0	13.6	2.2	50	189	5446	....	....
2 "	2675	66	3.4	11.0	2.5	45	155	4313	97,000	1,000
3 "	2100	72	3.2	10.4	3.2	51	107	5583	....	....
4 "	1600	80	3.6	10.8	3.8	42	87	3325	33,000	1,000
5 "	1350	48	3.4	11.0	3.2	37	97	2840	....	....
6 "	100	56	4.8	12.8	2.4	48	126	540	25,000	1,000
7 "	47	108	4.2	13.4	1.4	52	90	433	....	....
8 "	38	72	4.6	15.4	1.3	50	97	342	....	....
9 "	36	80	5.8	10.2	1.2	49	80	312	....	....
10 "	37	72	5.4	9.0	1.6	35	65	262	....	10,000
11 "	32	70	5.6	9.4	1.1	33	47	230	....	....
12 "	29	64	4.8	7.2	1.0	22	42	170	....	10,000
1 a. m.....	23	56	3.2	5.6	1.1	15	21	108	....	....
2 "	21	48	2.0	5.2	1.0	14	18	115	....	1,000
3 "	17	46	1.8	3.0	1.3	15	9	93	....	....
4 "	14	42	1.6	2.4	1.2	9	14	92	150,000	10,000
5 "	17	42	2.0	3.6	1.4	15	17	122	....	....
6 "	20	56	3.6	10.0	1.3	24	42	182	51,000	100,000
7 "	1350	68	5.4	17.0	1.2	34	87	2655	362,000	10,000
Average	1058	70	4.4	10.4	2.0	37	104	2275	88,500	12,100

The chlorine content of the sewage evidently varied widely between day and night, dropping from 1350 to 100 parts per million between 5 and 6 p. m., and increasing from 20 to 1350 parts per million between 6 and 7 a. m. The presence of a trade waste in the sewage was suspected from these results, and in order to determine its source samples were taken at various manholes from the outfall of the sewer upward along its course. The results of the chlorine determinations are shown in the third column of Table III, in which there is recorded an increase from 71 to 2700 parts per million between two sampling points (Nos. 6 and 7). The largest factory in the section of the city between the two manholes in question was the Candee Rubber Company. Inquiry proved that this

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was the concern which was increasing the chlorine content of the sewage. The Candee Company pumps 2,000 gallons of sea water per minute from the Mill River to be used for cooling purposes; and the water after use is discharged into the East Street sewer within one thousand feet of the Experiment Station. During the working day from 7 a. m. to 6 p. m. this would add 1,200,000 gallons of sea water to the sewage, or approximately 10 per cent of the total daily flow. The sea water contains an average of 12,000 parts per million of chlorine, the sewage an average of 1060, indicating analytically a dilution of approximately 10 per cent, as would be expected from the actual quantities involved.

During the latter half of the experimental work, from January 1 to May 1, 1918, this sea water was not discharged into the sewer, as a break occurred in the Company's suction line, which could not be repaired. The effect of the removal of this sea water is shown in Table VI and will again be referred to later on.

Low Bacterial Content due to Disinfectant Action of Copper in the Sewage. The twenty-four hour test discussed above revealed other peculiarities in the sewage. It was surprising to find a maximum of 97,000 bacteria per cubic centimeter in the day sewage, and only 4,500 per cubic centimeter at 10 a. m., a time when normally there should be several million. The presumptive test for *B. coli* indicated a maximum of only 1,000 per cubic centimeter throughout the daytime, although this content did increase to 100,000 per c.c. at 6 a. m. These facts suggested the presence of another trade waste of a bactericidal nature; and the analysis of samples from manholes at different points along the sewer served to trace this factor also to its source, as shown in Table III.

TABLE III. Copper and Chlorides in Samples of New Haven Sewage Collected at Different Points on the East Street Sewer.

Description of Sample	No.	Parts per Million			Bacteria per c.c. 20°C	Gas Formers per c.c. 27°C
		Alkalinity	Chlorine	Copper		
Near source of sewer.....	1	54	67	0.0	990,000	100,000
Below Winchester Arms Co.	2	90	144	8.8	3,000	100
	3	165	74	5.6	3,000	1,000
Small branch sewer	4	134	72	0.0	559,000	10,000
Main sewer	5	...	..	...	70,000	100
	6	156	71	1.9	380,000	10,000
Below Candee factory	7	90	2700	3.5	65,000	1,000
Experiment Station	8	130	2500	...	53,000	1,000

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It is obvious that the germicidal waste entered between Stations 1 and 2, as indicated by the sudden drop of the bacterial content from 990,000 to 3,000 per cubic centimeter . The wastes which enter at this point come from the Winchester Repeating Arms Company, a firm which uses large amounts of sulphuric acid in "pickling" brass shells. This "pickling" dissolves the scale of copper oxide formed on the shells during the annealing process. The copper oxide goes into solution as copper sulphate. Determinations of copper in the sewage as shown in Table III are so closely correlated with bacterial content as to make it certain that this metal is responsible for the partial disinfection of the sewage. The germicidal influence of the copper ion is too well known to require discussion. The fact that all samples were alkaline, however, indicates that the copper was not present in the sewage as sulphate, but that the alkalinity of the sewage was more than sufficient to neutralize the acidity of the waste, changing the copper sulphate into the basic carbonate, which is gradually precipitated as the hydroxide. The reactions which take place are as follows:

(1) $2\,CuSO_4 + 2\,Ca(HCO_3)_2 = CuCO_3Cu(OH)_2 + 2\,CaSO_4 + 3\,CO_2 + H_2O$

(2) $CuCO_3.Cu(OH)_2 + H_2O = 2\,Cu(OH)_2 + CO_2$

The organic matter in the sewage retards reaction (2), and the bactericidal action is probably mainly due to basic copper carbonate in colloidal solution. The diurnal variation in copper content and the accompanying variations in bacterial content and alkalinity as well as stability are shown in Table IV.

TABLE IV. Disinfectant Action of Copper on East Street Sewage. Aug. 10, 1917.

Time	Parts per Million				Hours Decolorization Methylene Blue		Bacteria per c.c.	Gas Formers per c.c.
	Chlorine	Alkalinity	Iron	Copper	Undiluted	1 sewage 2 water	20°C	37°C
6 a. m.	30	94	0.1	0.56	6	120	3,700,000	100,000
7 "	3750	136	0.2	1.52	6	24	.....	.....
8 "	3100	160	5.0	1.36	24	72	2.500,000	1,000,000
9 "	2900	101	1.8	2.88	48	120	.....	.....
10 "	2800	43	0.3	4.80	168	192	19,000	100
11 "	2750	114	0.4	2.72	60	144	.....	.....
12 "	2800	98	0.2	4.00	144	168	559,000	1,000
1 p. m.	3075	6	5.5	5.60	240	240	.....	.....
2 "	3200	86	0.6	1.92	24	72	187,000	10,000
3 "	3325	91	0.7	1.60	24	120	.....	.....
4 "	3375	88	0.2	1.92	48	96	39,000	100
5 "	3450	98	0.1	3.52	150	144	.....	.....
6 "	130	103	0.4	2.88	216	100	45,000	1,000
7 "	95	63	1.4	1.28	72	80	.....	.....
8 "	52	92	0.2	0.64	24	96	33,000	1,000
9 "	50	96	0.0	0.44	6	24	.....	.....

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These results indicate that the disinfecting action of the copper is strongest at 10 a. m. and 1 p. m. In order to study further the effect of the copper salts on bacterial content, samples were taken at 8 and 10 a. m. and 1 and 4 p. m. during the week of July 9-16, 1917. The results are shown in table V.

TABLE V. Bacterial Content of Sewage, Week July 9-16.

	Total Count, Agar, 20°C				Gas Formers, 37°C			
Day	8 a. m.	10 a. m.	1 p. m.	4 p. m.	8 a. m.	10 a. m.	1 p. m.	4 p. m.
Mon.	1,500,000	225,000	59,000	16,000	100,000	1,000	1,000	100
Tues.	1,080,000	128,000	6,000	7,500	100,000	100	1,000	100
Wed.	1,670,000	81,000	7,000	100,000	100,000	100	100	1,000
Thur.	1,100,000	148,000	1,500	12,000	100,000	10,000	100	10
Fri.	1,125,000	42,000	9,000	9,000	100,000	100	100	100
Sat.	.....	68,500	7,100	800,000	.....	100	10	*100,000
Aver.	1,295,000	115,400	14,700	159,000	100,000	1,900	385	17,000
Sun.,	.....	3,355,000	2,275,000	2,535,000	.....	100,000	100,000	100,000

*Factories shut down at noon Saturday.

During this week the number of bacteria in the sewage at 8 a. m. was approximately the same as would be found in any normal sewage. At 1 p. m., the time of greatest disinfecting action, the total number of bacteria was reduced to 14,700 per c.c., with only 385 *B. coli* per c.c. The bacterial content on Sunday is seen to be normal.

The determination of copper is rather tedious and it was not possible to make it as a routine, but it was found that if the raw sewage were incubated with methylene blue as is done in making stability determinations for effluents, the time of decolorization was roughly proportional to the amount of disinfectant present. This correlation is shown in Table IV.

Average Monthly Analyses. The average monthly analyses of the raw sewage are shown in Table VI, and a brief comment is made below on the significance of each of the principal determinations.

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TABLE VI. Average Monthly Analyses. East Street Sewage.

Month	No. Samples	Chlorine	Alkalinity	Ammonia N.	Nitrate N.	Turbidity	Suspended Solids		Settleable Solids 2 hrs. c.c. per liter	Temp. F.	Relative Stability 20°C
							Total	Volatile			
1917											
June	27	940	44	5.0	1.6	...	119	72	....	....	..
July	29	1022	57	4.6	1.5	...	92	57	2.20	....	38
Aug.	27	873	68	4.5	1.6	...	102	65	2.30	83.7	56
Sept.	24	960	68	4.1	1.4	220	88	58	1.90	77.1	48
Oct.	29	1260	68	3.4	1.5	247	109	67	2.50	71.7	59
Nov.	30	1300	69	4.6	1.9	238	105	70	2.12	64.8	37
Dec.	27	1081	59	4.8	1.7	255	100	63	2.25	53.0	51
1918											
Jan.	23	73	30	4.1	...	233	74	54	2.74	50.5	71
Feb.	27	49	30	...	...	...	104	61	2.90	49.0	73
Mar.	25	46	38	...	...	...	98	66	1.57	....	89
April	18	37	52	...	...	...	80	60	1.78	....	..
Average		695	53	4.4	1.6	238	97	63	2.22	64.3	58

Chlorine. Chlorine is generally taken as a measure of the strength of sewage, since its chief source is the salt used in the food. On the East Street sewer it serves rather as an index of sea water in the sewage. The sudden drop in the chlorine content in January was due as noted above to the elimination of the sea water used by the Candee Company for condensing purposes. It was to be expected that the removal of this large amount of water, amounting to approximately 10 per cent of the total flow, would result in an increase in the concentration of the sewage. On the contrary a decrease in concentration was indicated by a drop in suspended solids. This is probably due to the fact that an enormous amount of city water was wasted into the sewers during the very cold months of January and February in an effort to keep water pipes from freezing. The capacity of the New Haven Water Company was taxed to the utmost at this period.

Alkalinity. The determination of alkalinity on the raw sewage was of peculiar importance during these experiments in connection with the Miles process. The economy of this treatment depends to a large extent on the alkalinity of the sewage, as this alkalinity must be neutralized by the sulphur dioxide before the required degree of acidity can be obtained, and thus sewages with high alkalinities will require a larger amount of acid. The general alka-

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linity of 53 is exceptionally low as compared with the average alkalinity of Amercan sewages, which is usually over 100. This low alkalinity is due to the acid wastes from the Winchester Arms Company. The sewage is actually acid for a short time every day, and during the last four months this daily period of acidity lasted for several hours. This was mainly the result of increasing production at the Winchester Company, but may have been partly due to the absence of the sea water from the Candee Company's condensers.

Ammonia Nitrogen. The East Street sewage is exceptionally low in ammonia nitrogen, (a determination which measures organic matter in active decomposition), the average for American cities similar to New Haven being approximately 10 parts per million (instead of 4.4). This low ammonia content is probably in part due to the copper wastes, which prevent septic action in the sewage. The samples of raw sewage often stood in the laboratory for 24-48 hours without developing any odor, and without an increase in ammonia, even though they were not chloroformed. A few determinations of total organic nitrogen showed that it was about three times as great as the ammonia nitrogen. This ratio, also, is unusual as the ratio in a fresh sewage is usually nearer one to one. It is of interest to note that the average ammonia nitrogen in the Waterbury sewage, as determined at the testing station in 1906, was only 7.8 parts per million. This sewage was also reported to be unusually fresh and resistant to septic action. Copper wastes were undoubtedly the cause of this property at Waterbury, as now at New Haven, although this fact was not brought out in the reports of the Waterbury investigators.

Nitrate Nitrogen. The nitrate content of the sewage (indicating completely oxidized or mineral nitrogen) was quite uniform, varying between a minimum of 1.4 parts per million in September and a maximum of 1.9 parts per million in December. Because of this uniformity, determinations of nitrate nitrogen were discontinued in January.

The content of nitrate nitrogen is rather high for a raw sewage, as in most sewages denitrifying bacteria have usually reduced all of the nitrates by the time the sewage reaches the outfall. In this sewage, however, the copper wastes inhibit bacterial action and the reduction of the nitrates is correspondingly delayed.

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Total Organic Nitrogen. This determination was not made as a part of the regular routine, for lack of time, but a few determinations showed it to average 10 parts per million. The unusual ratio between the ammonia and organic nitrogen has been mentioned before, the copper wastes preventing ammonification of the organic matter such as would occur in a normal sewage.

Turbidity. The average turbidity of the raw sewage, as determined from September to January, was 238 parts per million. This determination is usually of little importance in sewage work, but was of interest in this investigation on account of the physical state of the matter in suspension in the effluents. The effluent from the Miles process and activated sludge process would often contain the same amount of suspended matter, and yet the former would have a colloidal, milky appearance with no clearly-defined suspended matter, while the latter would be perfectly clear except for numerous small flocculated particles. These properties seem to be specific for each of the effluents in question. The suspended matter in the activated sludge effluents will settle out on long, quiescent sedimentation, while that in the Miles effluent will not precipitate, but will remain in colloidal suspension.

Suspended Solids. This determination was considered the most important of all with regard to the comparative efficiencies of the processes under investigation, since these processes were essentially designed for the removal of suspended solids.

Very discordant results were obtained from month to month, varying from a minimum of 74 parts per million in January to a maximum of 119 in June, 1917. The low results in January were probably due to the increased waste of water during the excessively cold spell. The low results in April may have been due to the use of large quantities of water in the munition works. The general average of 97 parts per million is an exceptionally low figure,—in fact this is probably the smallest amount of suspended matter in sewage reported from any of the testing stations in this country. The proportion of volatile suspended matter is relatively high, being 65 per cent.

Settleable Solids. The results of this determination (of the suspended matter which settles out in a glass cylinder in 2 hours)

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also show wide variations from month to month. A minimum of 1.57 cubic centimeters per liter was found in March, 1918, with a maximum of 2.90 cubic centimeters per liter the preceding month. In this determination, as in that of suspended matter, it is very difficult to get a representative sample of a sewage as fresh as this one. Many large masses of feces and paper are present in the sewage which are usually not caught in the small sampling bottle, and on the other hand, sometimes one of these large particles may be included, which will give results considerably higher than those representing a fair sample of the flow. Even when results of analyses of composite samples are tabulated by months, many discrepant results will be obtained which cannot be explained on any basis except that the samples were not representative ones.

The average result, 2.22 cubic centimeters per liter, would seem to indicate that $\frac{1{,}000{,}000 \times .00222}{\div (27 \times 7.5)} = 11.0$ cubic yards of sludge might be expected from the sewage in two hours, quiescent sedimentation. Sedimentation experiments did not, however, produce nearly as much sludge as this. Experience shows here, as elsewhere, that as an absolute measure of quantity of sludge this determination is of no value, but as a relative comparison of the settleable material in the raw sewage and effluents it has considerable significance.

Temperature. The temperature of this sewage is above the average, due to a large volume of hot water used in the Winchester factory, and the warm condenser water from several other plants. The minimum temperature was reached in February, 1918, at 49.0°F.

Relative Stability. This determination, which is made by observing the time taken for an easily reducible dye, methylene blue, to lose its color on standing in contact with a sample of sewage or effluent, is a measure of the relation between oxygen and easily oxidizable organic matter. As a result of bacterial action the oxygen combines with such organic material until it has been all used up and then the methylene blue, which is itself an oxidation product, is reduced and loses its color. This determination is not generally made with raw sewages since their stability is so low as to be of no significance. The East Street sewage, however, as shown in the last column of Table VI, has a fairly high stability,—or rather pseudo-stability,—because in this case the delay in the decolori-

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zation of the methylene blue is due not to the presence of free oxygen but to the inhibition of the reducing processes caused by the presence of copper. The determination is here, therefore, of some value, as showing the relative amounts of disinfecting substances in the sewage. Curves, drawn from the data given in Table IV, show that, during the daytime, the length of time required for decolorization of methylene blue varies directly with the copper content.

For the purpose of studying this reaction composite samples of sewage were incubated with methylene blue, and although as Lederer has shown, the colloidal matter absorbs some of the dye under such conditions, a fairly accurate record of decolorization time could be made. The monthly averages showed a distinctly higher "pseudo stability" toward the end of the test in the spring of 1918. This indicated that there was a greater amount of copper in the sewage; while as before noted, the sewage was acid much more frequently at the end of the tests than at the beginning. Boh determinations bear out the conclusion that the munition wastes increased appreciably in the spring of 1918.

Biochemical Oxygen Demand. The copper in the sewage made it impossible to determine the biochemical oxygen demand (the amount of oxygen needed to care for the reducing matter present) in the week-day sewage. The sewage was, however, usually free from copper on Sundays and holidays, and determinations of the oxygen demand were made on a few samples taken at these times by the methylene blue dilution method. A total of twenty-one determinations, using two or three dilutions for each determination, gave an average oxygen demand of 48 parts per million. This is unusually low, most sewages having a demand of from 100-200 parts. It is possible that some copper may have been present even in these samples, which might account in part for the low demand, but it is evident that the East Street sewage would be weak and subnormal biologically, even though the copper-bearing wastes were absent.

Other Chemical Determinations. A few determinations of oxygen consumed (from permanganate) were made on the raw sewage. An average value of 37 parts per million was obtained. The determination of fats was so unsatisfactory that it was dropped. It was necessary to evaporate several liters of sewage in order to get a weighable amount of fat, and the large volume of salts from the

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sea water in the sewage prevented satisfactory extraction. A few determinations indicated that the fat content was from 10-15 parts per million. Occasional determinations of total iron varied from .6 to 12.0 parts per million.

Bacterial Content. As a result of the disinfectant action of the copper salts discharged by the Winchester Repeating Arms Company it appeared, as soon as we began our studies, that the bacterial content of the East Street sewer was distinctly abnormal. In order to determine the bacterial condition of the sewage in the absence of this disturbing element we collected a special series of samples at 8 a. m., on the assumption that at this time the effect of the copper would not be manifest; and a considerable number of samples were collected with the same end in view on Sundays and on holidays and on Saturday afternoons.

TABLE VII. Bacterial Content of East Street Sewage.

Week Day Samples. Monthly Averages.

Month	8 a. m. Samples			Week Day Samples exclusive of 8 a. m.		
	Number Samples	Bacteria per c.c.	B.coli per c.c.	Number Samples	Bacteria per c.c.	B.coli per c.c.
June, 1917.....	6	1,604,000	55,000	32	368,000	4,000
July "	13	1,223,000	234,000	49	144,000	5,000
Aug. "	4	856,000	280,000	24	185,000	5,000
Sept. "	2	901,000	55,000	27	174,000	18,000
Oct. "	12	1,231,000	129,000	21	251,000	9,500
Nov. "	12	809,000	24,000	28	165,000	8,000
Dec. "	14	177,000	22,000	13	23,000	3,000
Jan., 1918.....	16	105,000	18,000	17	41,000	14,000
Feb. "	13	99,000	8,000	11	80,000	4,000
Mar. "	14	84,000	14,000	14	80,000	16,000
April "	7	147,000	10,000	5	71,000	5,000

The monthly average results of the week day samples collected at 8 a. m. and at other times are brought together for comparison in Table VII. The 8 a. m. samples showed fairly high counts for the first six months of the study, but after November 1917 they dropped to low values almost the same as those recorded throughout for the week day samples taken after 8 a. m. This change was coincident with the beginning of night shifts at the Winchester works. Before December, 1917, the 8 a. m. samples therefore represent fairly normal sewage (with some disinfection due to residual copper from the day before); but after this month all week-day samples

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are of disinfected sewage. The increase in the work of the munition factory after November, 1917, is also shown in the further reduction of the bacterial content of the samples collected after 8 a. m.

In the interpretation of the studies on chlorine disinfection we divided all our samples into two groups, as shown in Table VIII. Sunday samples, Saturday afternoon samples and week-day 8 a. m. samples prior to December, 1917, have been considered as normal sewage (although all but the Sunday samples show some residual action of the copper salts); week-day samples collected after 8 a. m. from June to November and all week-day samples collected after November have been classed as sewages containing copper salts.

TABLE VIII. Bacterial Content of East Street Sewage.

	Number Samples	Bacteria per c.c.	B.coli per c.c.
Sunday samples	33	2,103,000	203,000
Saturday p. m. samples	13	1,156,000	44,600
Week day 8 a. m. samples, June-Nov.	49	1,127,000	129,100
Average for normal sewage	95	1,470,000	143,200
Sewage containing copper salts. Week day samples other than 8 a. m., June-Nov. All week day samples Dec.-Apr.	305	160,200	9,600

Bacteria per c.c. on agar incubated for 3 days at 20°C.
B.coli, gas formation in lactose broth incubated for 2 days at 37°.

Reference to Table VIII shows that when the copper salts were absent the East Street sewage was a normal rather weak city sewage from a bacteriological standpoint. When the copper wastes were being discharged on the other hand its content of bacteria was reduced to about 11 per cent of normal and its content of gas-forming organisms still further, to 7 per cent of the normal value.

It might be suggested that the partial disinfection of the East Street sewage by the copper salts from the munition factory accomplishes a large part of the task which might otherwise fall upon a sewage purification plant; and to some extent this is the case. On the other hand the effect of such adventitious disinfectants is normally limited to the day flow of sewage and even then the results accomplished are not equal to those which we believe necessary for an effluent to be discharged into New Haven harbor. Furthermore we find that in order to reduce the bacterial content to a sufficient degree nearly as much chlorine is required as would be needed for an ordinary city sewage, the bacteria, and even the gas formers

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which survive the exposure to copper, either having an intrinsically high resistance or being imbedded in masses of suspended matter.

It appears too that a certain proportion of the bacteria in the sewage are not killed outright by the copper salts, but are merely so injured that they can grow very slowly. At the beginning of our work it was found that the development of colonies on plates made from the East Street sewer was unusually slow and for this reason a three day period of incubation was chosen, instead of the two day period called for by standard methods. Even three days' incubation does not of course permit the development of all viable organisms; and it appeared from later studies that the proportion of slowly growing forms is much greater in the case of the sewage containing the antiseptic industrial wastes. To obtain light on this point plates made from 70 samples of normal sewage (Sunday and 8 a. m. samples), and from 68 samples of week-day sewage containing the copper wastes, were incubated for a week and counts made after 3 and 7 days. From the first counting to the second the plates made from the normal sewage showed an average increase in count of 93 per cent; while the plates made from the sewage containing the munitions wastes showed an average increase of 203 per cent. A still more striking comparison is offered by a series of samples in which the amount of copper present was roughly estimated by the depth of the red color on the mat in the Gooch crucible used for determining suspended inorganic solids. Thirty-four samples, classified as of low copper content in this way, gave an increase of 101 per cent in colony count between the third and the seventh day of incubation; while 13 samples of high copper content gave a corresponding increase of 349 per cent.

The same phenomenon, of delayed colony development on plates, was manifest to an even more marked degree with the Miles acid effluent, no doubt as a result of the action of the sulphur dioxide. Sixty samples of effluents of this type showed an average increase of 560 per cent between the fourth and the seventh day of incubation. With chlorinated effluents no such effect was manifest. Twenty-four samples of effluents treated with 6-8 parts of chlorine showed an increase of only 100 per cent between the 3 and 7 day counts.

General Characteristics of the East Street Sewage. It appears from the various results, which have been cited above, that the

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East Street sewage is abnormal in almost all respects. It is the weakest sewage studied at any of the sewage testing stations in the United States, and it contains large amounts of an unusual waste which profoundly affects its chemical and bacterial properties. The presence of copper in sewage has not been noted by any other investigators in this country. It is fortunate that the effect of this disinfectant on biological processes such as the activated sludge and Imhoff tank could be studied experimentally and the difficulties foreseen which must have been encountered had such biological processes been installed on a large scale.

Composition of the Boulevard Sewage. The small testing station at the Boulevard sewer was operated from March 22 to April 21, 1918. Composite samples were collected here in the same manner as at East Street and the same analytical determinations were made. The average results are shown in Table IX.

TABLE IX. Boulevard Sewage.

No. of Samples	Chlorine	Alkalinity	Ammonia Nitrogen	Suspended Solids Total	Suspended Solids Volatile	Settleable Solids	Biochemical Oxygen Demand
30	46	126	15.6	120	84	1.99	101

This sewage is quite different from the East Street sewage. The alkalinity is about twice as high, the ammonia nitrogen and the oxygen demand each three times as great. The suspended solids are a little higher, and the settleable solids lower.

The sewage seemed to the eye much stronger than the East Street sewage, but this appearance was largely due to a difference in the physical condition of the suspended matter present. The suspended solids in the Boulevard sewage are in a very fine state of division, and the sewage has a milky appearance in consequence. The suspended solids in the East Street sewage are in larger lumps, while the liquid itself is not so opaque. One reason for the finely comminuted condition of the Boulevard sewage is that on this sewer there are about a dozen drop wells, points at which sewage is precipitated into the main sewer from branch sewers at considerable distances above. The Boulevard sewage contains a large amount of soap and very little grit, and practically all of the industrial wastes discharged into it are those from laundries. These wastes may account for the relatively high alkalinity. This high alkalinity was

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very detrimental to the Miles process, as the sewage required almost twice as much sulphur dioxide to acidify it as was required at the East Street outfall. Although the suspended solids are higher than are those in East Street sewage, the settleable solids are lower. This means that the suspended matter in the Boulevard sewage will not settle out as readily as that in the East Street sewage, and that the solids are not in as desirable a condition for screening as are those present in the latter case. The biochemical oxygen demand is about what would be expected in a sewage of this strength. In short, this sewage may be described as a normal weak domestic sewage containing its suspended matter in a finely-comminuted state.

The bacteria in the Boulevard sewage, during the month for which analyses were made, averaged 1,875,000 bacteria and 221,000 *B. coli* per c.c., a normal value for an average city sewage.

RESULTS OF FINE SCREENING

The process of fine screening has been strongly advocated by prominent engineers as an alternative to various forms of sedimentation for the preliminary treatment of the sewage. Experiments at Philadelphia indicated a removal of 33 per cent of suspended solids, and at Cleveland similar experiments showed a removal of 25-28 per cent; while the manufacturers of the screening apparatus make even more glowing claims. In view of the freshness of the East Street sewage we anticipated that its suspended matter would be in a very favorable condition for removal by fine screening, and we therefore devoted considerable attention to the possibilities of this process.

The methods used in our screening experiments have been described on page 28. Altogether 28 tests were conducted with the East Street sewage and four with the Boulevard sewage, the results obtained being indicated in Table X and the characteristics of the screenings themselves in Table XI.

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TABLE X. Purification Effected by Fine Screening.

Date	Sewage screened gallons	Wet screenings, Lbs. per mil. gals.	Solids in screenings, Lbs. per mil. gals.	Suspended solids p.p.m. Inf.	Suspended solids p.p.m. Eff.	Per cent reduction	Settl. Solids per cent reduction
			East Street, Wire-Mesh Screens				
6/22 '17	2130	1700	248	150	120	20	..
7/5	1775	1375	183	104	82	21	..
7/6	2059	1185	152	133	115	14	..
7/18	2414	1011	167	121	101	16	..
7/19	2414	1085	173	113	92	18	..
8/2	1917	1304	211	145	120	17	..
8/3	3185	745	123	130	115	12	..
8/15	2092	1555	191	177	154	13	..
8/16	2835	1145	207	124	99	21	..
10/29	1610	1445	150	154	136	12	..
11/5	1352	2448	310	179	141	21	..
11/7	2190	1283	149	128	110	14	57
11/8	2510	1120	154	125	107	14	40
11/9	2447	1200	132	122	106	13	..
11/13	1513	2070	271	156	124	20	60
11/14	1932	1490	156	150	131	13	38
11/15	1996	1503	165	162	142	13	14
11/17	2220	1351	140	119	102	15	10
11/28	2512	995	97	136	125	8	55
12/4	2447	1022	132	158	142	10	11
12/6	1739	1616	181	114	92	19	66
12/7	1739	1437	217	279	256	9	..
Average	2138	1367	178	145	123	15	41
			East Street, Plate Screens.				
3/4 '18	3477	757	92	184	173	7	0
3/6	3864	631	99	111	99	11	33
3/7	3477	647	70	132	123	7	20
3/8	3284	743	102	144	132	9	33
3/9	2898	690	81	110	100	9	..
3/11	3606	522	73	139	126	8	29
Average	3434	665	86	137	126	8	29
			Boulevard, Wire-Mesh Screens.				
3/20 '18	1789	1570	149	133	115	14	62
3/22	1112	1124	128	135	120	11	25
Average	1450	1347	138	134	117	12.3	43
			Boulevard, Plate Screens.				
3/20 '18	5850	224	23	157	154	2	29
3/22	5967	440	33	114	110	4	..
Average	5908	386	28	135	132	3	29

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TABLE XI. Analyses of Screenings.

Date	Sp. Gr.	Moisture	Solids	Volatile	Fixed
		East Street, Wire-Mesh Screens.			
6/21/17	1.035	85.5	14.5	71.0	29.0
6/22	1.046	85.4	14.6	66.0	34.0
6/8	1.041	86.7	13.3	70.1	29.9
7/6	1.028	87.2	12.8	75.3	24.7
7/18	1.035	83.5	16.5	76.7	23.3
7/19	1.031	84.1	15.9	72.1	27.9
8/2	1.055	83.8	16.2	68.3	31.7
8/3	1.042	83.5	16.5	67.3	32.7
8/15	1.025	87.7	12.3	74.0	26.0
8/16	1.020	81.9	18.1	67.4	32.6
10/29	1.032	89.6	10.4	77.3	22.7
11/5	1.037	87.1	12.9	73.1	26.9
11/7*	1.025	88.4	11.6	70.7	29.3
11/8	1.038	86.2	13.8	....	....
11/9	1.035	89.0	11.0	79.5	20.5
11/13	1.017	86.9	13.1	72.5	27.5
11/14	1.034	89.4	10.6	66.2	33.8
11/15	1.024	89.0	11.0	76.5	23.5
11/17	1.033	89.6	10.4	71.5	28.5
11/28	....	90.3	9.7	66.2	33.8
12/4	1.051	87.1	12.9	58.3	41.7
12/6	1.036	88.8	11.2	70.5	29.5
12/7	1.037	84.9	15.1	65.2	34.8
Average	1.034	86.8	13.2	70.7	29.3
		East Street, Plate Screens			
3/4/18	10.28	87.8	12.2	84.2	15.8
3/5	1.034	88.7	11.3	76.6	23.4
3/6	1.039	84.3	15.7	84.5	15.5
3/7	....	89.2	10.8	82.1	17.9
3/8	1.027	86.2	13.8	83.4	16.6
3/9	1.042	88.3	11.7	81.4	18.6
3/11	1.043	86.0	14.0	82.1	17.9
Average	1.035	87.2	12.8	82.0	18.0
		Boulevard, Wire Mesh Screens.			
4/21/18	1.050	90.5	9.5	77.5	22.5
3/21	....	88.6	11.4	78.9	21.1
Average	1.050	89.6	10.4	78.2	21.8
		Boulevard, Plate Screens.			
3/20/18	1.011	89.9	10.1	81.4	18.6
3/22	1.019	92.7	7.3	82.5	17.5
Average	1.015	91.3	8.7	82.0	18.0

*Dried screenings contained 1.96% Nitrogen.

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To consider first the results obtained with the East Street sewage, it appears that the wire mesh screens (30 meshes to the inch) effected a reduction in suspended solids varying from 8 to 21 per cent and averaging 15 per cent. The weight of wet screenings produced varied from 745 pounds to 2448 pounds, and averaged 1367 pounds, per million gallons of sewage treated. The water content of the screenings (see Table XI) varied between 81.9 per cent and 90.3 per cent and averaged 86.8 per cent. The water content appeared to be somewhat less in summer than in winter, perhaps as a result of higher viscosity in cold weather. The proportion of the solid material which was of organic nature varied from 58.3 per cent to 79.5 per cent and averaged 70.7 per cent.

The plates screens proved much less satisfactory than those of wire mesh. The per cent removal varied from 7 to 11 per cent and averaged only 8 per cent; while the wet screenings varied from 522 to 757 pounds, and averaged 665 pounds, per million gallons of sewage treated. In other words the plate screens with 1 1/4x1/16 inch slots took out only about half as much of the suspended solids as did the wire screens with 30 meshes to the inch. The moisture content of these screenings was somewhat higher than in the case of the wire mesh screens (87.2 against 86.8 per cent) and the organic solids were considerably higher (82.0 against 70.7 per cent). It is evidently the fine inorganic materials which pass most readily through the plate screen.

Even the four experiments made on the Boulevard sewer were sufficient to show that this sewage is even less amenable to screening treatment than that at the East Street outfall. Wire mesh screens removed only 12 per cent of the suspended solids, here, and plate screens only 3 per cent. The screenings obtained at the Boulevard plant contained more moisture than those at East Street (89.6 per cent against 86.8 per cent for wire screens, 91.3 per cent against 87.2 per cent for plate screens). The ineffectiveness of screening at this sewer was obviously due to the highly comminuted state of its suspended solids, to which reference has been made above. It is interesting to note by reference to the first column of figures in Table X that this finely divided suspended matter passed so easily through the plate screen that 5908 gallons of sewage were treated before the loss of head reached 2 feet, as against only 3454 gallons for the same type of screen at East Street.

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Altogether it seems evident that fine screening, with either wire screens (30 meshes to the inch) or plate screens (1¼ x 1/16 inch slots) cannot be expected to accomplish any important degree of purification with either of the sewages studied. Such screens will of course remove the grosser and more obvious floating solids and, where it is only necessary to avoid visual offense, they may be of great value. Where a substantial removal of suspended solids is desired, such as is accomplished by tank treatment, fine screens will not serve.

Our results are in accord with the general conclusions of conservative sanitary engineers. Mr. George W. Fuller, who is a firm believer in fine screening for situations to which it is adapted, estimates only a removal of 10 per cent of suspended solids by such treatment. It is quite certain that a full-size installation of moving screens would accomplish less than the purification indicated by our tests. At Cleveland as noted above preliminary studies made like our own with stationary hand-operated screens gave a removal of 25-28 per cent, while an actual Riensch-Wurl installation (on another outfall sewer of the city) took out only 4 per cent of the suspended solids present. Any such degree of purification as was indicated by our studies, or by the Cleveland experience (and both are entirely in accord with conservative engineering opinion) would, in our judgment, be inadequate for an effluent to be discharged into a shallow harbor with a narrow dredged channel, like that with which we are dealing at New Haven.

RESULTS OF IMHOFF TANK TREATMENT.

As noted on page 32 our experiments with Imhoff tank treatment began in November 1917, and extended for a period of six months to April, 1918. It was of course unfortunate that operation should have begun in the winter time, but by the end of April the increasing warmth of the season should have brought about normal activities in the tank, if other conditions had been favorable. Yet the results were at no period satisfactory, and they became worse and not better as time went on.

Table XII shows the monthly averages for various constituents of the tank effluent and the per cent purification represented by these figures compared with the corresponding values for the crude sewage.

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TABLE XII. Results of Treatment of East Street Sewage by Imhoff Tank.

Month	Number Analyses	Alkalinity p.p.m.	Per cent removal	Ammonia N p.p.m.	Per cent removal	Turbidity p.p.m.	Per cent removal	Suspended Solids p.p.m.	Per cent removal	Volatile Susp. Solids p.p.m.	Per cent removal	Settleable Solids c.c. per liter	Per cent removal
Nov.	25	71	-3	6.1	-32	215	9	56	47	41	41	.38	82
Dec.	27	67	-14	5.1	-6	199	22	53	47	39	38	.35	82
Jan. '18	25	47	-57	4.1	0	208	11	41	45	31	43	.41	85
Feb.	27	38	-27					55	47	44	28	.32	89
Mar.	24	35	8					60	40	40	39	.80	43
Apr.	20	40	23					52	35	38	37	1.16	35
Average		50	-12	5.1	-13	207	14	53	43	39	38	.57	69

-Sign denotes increase.

The alkalinity of the sewage was increased by 12 per cent in passing through the tanks. In January when the alkalinity of the crude sewage fell off about a half as a result of the elimination of the Candee condenser water, the alkalinity of the Imhoff effluent was not reduced in a corresponding degree, so that for the two months of January and February the increase in alkalinity was very great. In March and April on the other hand the tank reduced the alkalinity of the sewage passing through it. We are somewhat at a loss to account for these variations which, however, suggest marked irregularities in the bio-chemical processes going on within the tank.

Determinations of ammonia nitrogen and turbidity were made only for three months and show a normal increase of the former constituent and a moderate decrease in turbidity.

The most important criterion of the success of tank treatment is to be found of course in the removal of suspended solids; and from this standpoint the operation of the tank was disappointing. The average removal of total suspended solids was only 43 per cent, of volatile suspended solids, only 38 per cent, and of settleable solids only 69 per cent. A satisfactory Imhoff tank should remove half of the total suspended solids and nine-tenths of the settleable solids. With so weak a sewage as that of the East Street outfall it is difficult to secure a high removal of suspended solids by sedimentation, a conclusion borne out by a two months' experiment with plain sedimentation of this sewage which effected a 41 per cent

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removal of suspended solids, a result practically identical with that obtained from the Imhoff tank.

It is interesting to note that the Imhoff effluent was distinctly worse, from the standpoint of its content of settleable solids, during the last two months of operation than at any previous time. There was, however, no obvious foaming or other unduly active fermentation going on in the tank to which such a result might be attributed.

The bacterial content of the Imhoff effluent is indicated in Table XIII. The general averages given represent a removal of 32 per cent of the total bacteria and 85 per cent of the colon bacilli in the normal sewage,—and a removal of 35 per cent of the total bacteria and 76 per cent of the colon bacilli in the sewage containing the copper wastes.

TABLE XIII. Bacterial Content of Imhoff Effluent.

Month	Normal Sewage			Sewage containing copper wastes		
	No. samples	Bacteria per c.c.	B.coli per c.c.	No. samples	Bacteria per c.c.	B.coli per c.c.
Nov. '17	8	2,178,000	19,000	4	922,000	2300
Dec.	1	485,000	100,000	10	201,000	7000
Jan. '18	5	132,000	8,000	25	55,000	2000
Feb.	3	104,000	37,000	20	40,000	1400
Mar.	2	118,000	5,000	18	37,000	800
Apr.				9	47,000	2400
Average		1,005,000	21,700		104,000	2300

At the close of these experiments sludge was drawn from the Imhoff tank and found to be reddish brown in color and highly offensive, having not at all the characteristics of normal well ripened Imhoff sludge. It contained on a dry basis 1.74 per cent of nitrogen and 12.1 per cent of ether extract. When the attempt was made to dewater the sludge on a small sand bed it was found to dry very slowly instead of cracking and draining easily as Imhoff sludge should do. The peculiar nature of the sludge was not due to its reaction, which was alkaline, but presumably to the antiseptic action of the copper wastes, which at all points interfered with normal biological processes.

In general, it appears that when the East Street sewage is treated in an Imhoff tank a fair degree of purification is effected, a purification not as good as is usually attained by this process of

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treatment but probably sufficient for the local needs at New Haven. The peculiar character of the sludge, however, indicates that a normal digestion of sludge can hardly be hoped for in the presence of the industrial wastes which this sewage contains. In view of this fact there is reason to anticipate that the operation of an Imhoff tank at this outfall, and particularly the removal of the sludge from such a tank, might be productive at times of serious local nuisance. The foaming of Imhoff tanks with the production of foul odors has caused very grave difficulties at Plainfield, N. J., and other places and at Baltimore has led to the entire abandonment of the process.

ACTIVATED SLUDGE TREATMENT.

The activated sludge process was studied less as an oxidizing than as a clarifying process, in the same way in which it was used at Cleveland. It was thought that activated sludge treatment and chlorination might compete with Imhoff treatment and chlorination if the air and tank space required for the former process could be cut down considerably, and if the amount of chlorine required for disinfection were much less in the former case than in the latter, For this reason small amounts of air and short periods of aeration were used, and no attempt was made to obtain nitrification in the effluent. The activated sludge process is not as well adapted for clarification as for nitrification, since sludge does not possess as great a power for clarifying the sewage when it is not well aerated. Furthermore we had no secondary tank for the aeration of sludge alone, so that our equipment was not well adapted to studying activated sludge as a clarifying process. Good results were obtained at certain times, but on the whole the work with activated sludge was unsatisfactory. Results of operation are shown in Table XIV.

Continuous operation was started on June 1, 1918, with an aeration period of 2½ hours and a settling period of 55 minutes. The amount of sludge pumped back was excessive, amounting to 73/100 of the total amount of sewage treated. The sludge was very dilute, as shown by the fact that after 30 minutes' settling of the liquor returned to the aerating tank only 15 per cent of its volume was occupied by settled solid matter. On June 28, nearly four weeks after operation was started, there was only 60 per cent of settleable matter in the returned liquor, and only 11 per cent in the aeration

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tank. Aeration was stopped on June 28, and both tanks were emptied. During this first month of operation approximately 1.30 cubic feet of air per gallon of sewage was applied. The results obtained were unsatisfactory, as sludge did not accumulate nearly as rapidly as it has usually done at other places where activated sludge experiments have been conducted, and the effluents were not well purified. The removal of suspended matter was 71 per cent, better than was obtained on the average in succeeding months, but even this result was not nearly as good as should be expected from the activated sludge process under normal conditions.

On July 1 operation was resumed with less sludge-liquor returned (50/100) and less air (1.10 cu. ft. per gal.). As this did not seem to give any better results, on July 5 the quantity of sewage applied was cut down, so that a period of aeration of 3.25 hours and a settling period of 1.3 hours was obtained. The air was kept at 1.4 cubic feet per gallon of sewage, and the returned sludge at 65/100 of the sewage treated. Under these operating conditions practically no sludge accumulated, there being but 3 per cent settleable matter in the aerating tank and 11 per cent in the returned liquid on Aug. 1, 31 days after operation was begun. Operation was again interrupted, and the aeration tank was used on the fill-and-draw plan for a week, from August 2-9, using periods of aeration of from 3-10 hours and settling ½ hour with an aeration of 1.5 cubic feet per gallon of sewage. The results were very poor, as the sludge did not accumulate rapidly and that which did build up was of poor quality. The effluent appeared turbid and there was no sharp line of demarcation between sludge and sewage, such as is seen when the sludge is in good condition. Such a phenomenon is usually due either to under-aeration or over-aeration, but in this case it was not due to over-aeration as indicated by the fact that no increase in nitrate nitrogen was found in the effluent.

Even when aerated for 10 hours, results were no better. This period of operation on the fill-and-draw schedule proved that the poor results which had been obtained previously were not due to faulty operation of the continuous-flow process, but that they were due to some inhibitory substance in the sewage itself. For this reason continuous-flow operation was resumed on August 9.

From August 9-31 operation was uniform, the aeration period being 2.7 hours, settling period one hour, and air supply 1.30 cubic feet per gallon. Settleable matter in the aeration tank increased from

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5 to 7.5 per cent and in the settling tank from 14 to 38 per cent. Fairly good results were obtained during this period, and the sludge was of good appearance, but only 63 per cent of the suspended solids were removed and there was no appreciable increase in nitrates in the effluent.

During the month of September operation was more satisfactory than at any other time during the tests. During this month the sewage was aerated for 2.7 hours and settled for 1 hour. The sludge liquor returned to the aerating tank was 63 per cent of the raw sewage treated, and this liquor contained an average of 46 per cent of settleable matter, increasing from 34 per cent on September 1 to 60 per cent on September 30. The settleable matter in the aerating tank increased from 8 per cent to 17.5 per cent. Air was applied at the rate of 1.3 cubic feet per gallon of sewage.

The removal of suspended matter during this best period of operation was but 60 per cent and nitrates in the effluent averaged but 2.8 parts per million. The sludge was in good condition most of the time, but toward the end of the month it began to get colloidal, and the suspended solids in the effluent increased. Although the sides of the settling tank sloped at 60° a small amount of sludge stuck to the sides, but as the slopes were cleaned with a brush four times a day, there was little possibility of septic action occurring in these deposits.

In October the schedule of operation was practically the same as during September but instead of increasing, the settleable matter in the aerating and settling tanks decreased, being 11 per cent and 60 per cent respectively at the end of the month. Air was increased to 1.65 cubic feet per gallon. The sludge became colloidal and would not settle well. The effluent was turbid, a removal of only 51 per cent of the suspended solids being obtained. The removal of settleable solids, also, was poorer than during the preceding month, having decreased from 89 per cent removal to 84 per cent. A slight increase in nitrate nitrogen was obtained, from 1.5 to 2.3 parts per million.

In November operation was continued under the same conditions as in October, and the sludge steadily became worse, becoming very voluminous about November 18 (Sunday) and refusing to settle properly after that, even though the aeration period and quantity of air were increased. It was impossible to get the sludge in good condi-

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tion, even by aerating it alone for several days. It was thought that the large amount of grit in the sludge, as indicated by analyses, might account for its poor quality, so a supplementary grit chamber was placed on the trough feeding the activated sludge tank, which removed some of the grit and resulted in a decrease in the mineral matter in the sludge, but did not, however, improve its physical condition. A fairly good effluent was obtained in November, a removal of 67 per cent of the suspended solids and 95 per cent of the settleable solids being recovered. Very little increase in nitrates was observed.

On December 2 practically all of the sludge was lost through stoppage of the sludge-return-pipe, and on December 10 all of the pipes froze and several valves cracked. Sludge was aerated alone from December 10 to December 20. On the latter date operation was resumed, applying an excessive quantity of sewage from December 20-28 in order to accumulate sludge rapidly. The rate was cut down to 9 gallons per minute on December 28, but on account of the cold weather a large amount of sludge liquor had to be returned to the aerating chamber, amounting to considerably more than the quantity of raw sewage. Approximately 2 cubic feet of air per gallon of sewage was applied. The sludge was very voluminous and colloidal, and of poor quality. The effluents were unsatisfactory, but 50 per cent of the suspended solids and 82 per cent of the settleable solids being removed. Nitrates in the effluent were the same as in the raw sewage, and only 31 per cent removal of turbidity was accomplished, the effluent having an average turbidity of 175.

In January, operation was constantly interrupted by the cold weather, as the sludge pipes were of small size and were frequently frozen solid. The sludge became very voluminous and variations in operation would not improve its quality. The effluents were turbid, and there was very poor removal of suspended and settleable solids.

In February, operation was continued under difficulties until the 15th when the raw sewage was turned off and sludge alone aerated. Very little improvement in the effluents, as compared with the raw sewage, was noted during these 15 days. After February 15 sewage was no longer treated by the activated sludge process, the aeration tank being used simply for keeping the sludge aerobic for experiments with centrifugal drying.

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The operating results obtained with the activated sludge process were on the whole, therefore, quite unsatisfactory. This was partly due to the design of the settling tank, the lack of a separate sludge aerating tank, and the small size of the sludge pipes, but we are satisfied that the primary reason for the poor results was the presence of industrial wastes in the raw sewage, the copper being probably mainly responsible. The sludge was rarely well-flocculated, and did not settle well, even when aerated separately. The effluents did not have the brilliant clarity so characteristic of effluents from domestic sewages, and the removal of suspended solids was poorer than has been obtained at any of the testing stations in America where this process has been investigated.

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TABLE XIV. Results of Activated Sludge Treatment.

Month	No. analyses	Alkalinity p.p.m.	Alkalinity Per cent removal	Ammonia N p.p.m.	Ammonia N Per cent removal	Nitrate N p.p.m.	Turbidity p.p.m.	Turbidity Per cent removal	Suspended solids p.p.m.	Suspended solids Per cent removal	Volatile suspended solids p.p.m.	Volatile suspended solids Per cent removal	Settleable solids c.c. per liter	Settleable solids per cent removal	Stability
June '17	27	58	–32	4.0	20	1.5	...	..	34	71	24	67	...	..	..
July	28	68	–19	3.7	20	1.4	...	..	35	62	25	56	.32	85	..
Aug.	21	70	–3	3.8	16	1.7	75	..	38	63	26	60	.22	90	88
Sept.	24	62	9	3.3	20	2.8	80	64	36	60	23	60	.21	89	96
Oct.	23	70	–3	3.2	6	2.3	134	46	55	51	38	43	.41	84	94
Nov.	20	67	3	4.3	7	2.1	90	62	35	67	26	63	.19	95	94
Dec.	9	54	8	3.6	12	1.7	175	31	50	50	38	40	.40	82	87
Jan. '18	25	36	–20	3.9	5	1.6	197	15	45	39	33	39	1.30	53	87
Feb.	14	30	0	4.2	..	...	250	..	69	34	45	26	2.40	17	84
Average		57	–6	3.8	13	1.9	147	44	44	55	31	50	.68	74	90

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Bacterial Results. The bacterial content of the activated sludge effluent is indicated in Table XV. With the methods of operation which we used and with the peculiar sewage treated, the purification effected was not marked. The effluents, as indicated in the table, averaged over 800,000 bacteria per c.c., an actual increase as compared with the crude sewage containing copper wastes; while the colon bacilli averaged 9780 for the normal sewage (a reduction of 93 per cent) and 2600 for the sewage containing the copper wastes (a reduction of 73 per cent).

TABLE XV. Bacterial Results of Activated Sludge Treatment.

Month 1917	Number samples	Effluent from Normal Sewage Bacteria per c.c.	Effluent from Normal Sewage B.coli per c.c.	Number samples	Effluent from Sewage containing Copper wastes Bacteria per c.c.	Effluent from Sewage containing Copper wastes B.coli per c.c.
June	7	820,000	230	8	2,075,000	550
July	2	2,322,000	550	2	2,040,000	100
Aug.	1	40,000	1,000	1	64,000	100
Sept.	6	732,000	20,500	20	374,000	3,250
Oct.	13	415,000	12,000	18	564,000	2,900
Average		983,000	9,780		824,000	2,600

TABLE XVI. Analyses of Activated Sludge.

Date	Per cent on dry basis Moisture	Volatile matter	Nitrogen	Ether extract
June 16, 1917	94.4	43	2.89	5.2
June 23, 1917	94.0	42	3.05	5.4
Sept. 25, 1917	94.2	50	4.45	...
Nov. 15, 1917	94.8	53	3.51	...
Average	94.3	47	3.23	5.3

Character of Sludge. The sludge obtained from this process of treatment had an unusually low moisture content, averaging 94.3 per cent. This is much below the 98-99 per cent usually found at other places, and is partly due to the grit in the sewage, but also in part to the character of the mineral matter in the suspended solids in this sewage, derived from the industrial wastes. The volatile matter is low, and the nitrogen content very low. Interest in the activated sludge process has generally centered in the unusually high content of nitrogen in the sludge, but in this sludge the nitrogen content is so low as to be almost in the class of non-utilizable sludges, such as Imhoff, septic and chemical precipitation sludges. It might

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be increased slightly by well-designed grit chambers, but at best would be abnormally low.

The ether extract of the activated sludge (5.3 per cent) is low as compared with the 20-30 per cent in the Miles sludge and the 12 per cent in the Imhoff sludge.

Special Features of Operation. The filtros plates gave a very satisfactory distribution of air when first installed, but deposits of iron rust on the lower surfaces caused uneven distribution after four or five months' operation. The plates could usually be cleaned by releasing the air pressure and allowing the liquid to filter through them so as to wash off the deposits. The resistance to the air increased one-quarter of a pound in the ten months' operation of the tank.

The Nash hydro-turbine was very satisfactory, but required a rather large amount of power for operation. It gave a very steady current of air, which could be measured satisfactorily by means of the Venturi meter.

The slopes of 60° in the bottom of the settling chamber were not sufficient to avoid deposits of sludge. The prevention of these deposits is an essential for successful operation of the activated-sludge process.

The costs of the activated sludge process for New Haven sewage have not been estimated, because we feel certain that activated sludge should not be considered for the East Street sewage. Trade wastes interfere too markedly with the proper biological conditions demanded, and very careful manipulation of the sludge would be necessary in order to keep it in good condition.

The sludge is unusually low in nitrogen and the recovery of this constituent would hardly be worth while. The cost of power would probably be 2 cents per kilowatt hour, a fact which in itself is practically sufficient to eliminate this process. All things considered, activated sludge treatment does not seem to be suitable for New Haven sewage.

RESULTS OF EXPERIMENTS ON CHLORINATION OF SEWAGE AND EFFLUENTS.

In addition to determining the efficiency of various treatments for the removal of suspended solids, it was necessary to study the effect of subsequent chlorination of the screen and tank effluents

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and to gain an idea of the amount of chlorine necessary to produce a given result in each case. As a basis of comparison it was thought best to conduct a similar series of tests on the chlorination of the crude sewage.

In order to interpret our results it was necessary to fix on some tentative standard which might be considered as adequate and satisfactory. For this purpose we have assumed as the ideal to be attained that the final disinfected effluent should contain not over 10,000 bacteria and not over 1000 colon bacilli per c.c. as a general average. This represents a purification of over 99 per cent for the normal East Street and Boulevard sewages and a purification of about 90 per cent for the East Street sewage containing the copper wastes. On the basis of Mr. Kellogg's estimate of a 1 in 300 dilution, and ignoring other sources of pollution, the bacterial content of the harbor waters as a whole should be reduced, with this degree of sewage purification, to 30 bacteria and 3 colon bacilli per c.c.

Chlorination of Crude Sewage. The results obtained by chlorination of the crude sewage at the East Street outfall are shown in Table XVII. It is evident that with the normal sewage 8 parts of chlorine are necessary to produce the desired degree of purification; while with the day flow contained the copper wastes 5 parts appeared to be adequate in a series of twelve samples tested with this concentration.

TABLE XVII. Results of Chlorination of Crude Sewage.

Chlorine p.p.m.	No. tests	Unchlorinated Bacteria	Unchlorinated B.coli	Chlorinated Bacteria	Chlorinated B.coli	Per cent reduction Bacteria	Per cent reduction B.coli
		Normal Sewage.					
3	13	2,736,000	227,000	341,000	104,000	87	55
5	9	1,282,000	248,000	56,000	1,500	96	99
7	3	1,180,000	10,000	28,000	3,400	98	66
8	2	620,000	10,000	3,100	550	99	94
		Sewage Containing Copper Wastes.					
3	56	160,000	6,400	28,400	3,100	82	52
5	12	134,000	4,500	3,100	1,100	98	75
7	18	161,000	4,800	14.600	800	91	83
8	15	58,000	20,800	7,100	2,900	88	86

Chlorination of Screened Sewage. It was expected that the removal of the larger particles of suspended matter by fine

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screening would make disinfection by chlorine more efficient than in the case of the crude sewage. That such is to some degree the case is suggested by the results presented in Table XVIII.

Both the normal sewage and the week-day sewage containing the copper wastes, after fine screening, could be brought approximately to our standard of bacterial content by the use of 5 parts of chlorine, although here as in all such experiments there are naturally individual discrepancies. Three parts of chlorine is, however, clearly insufficient.

TABLE XVIII. Results of Chlorination of Screened Sewage.

Chlorine p.p.m.	No. tests	Unchlorinated Bacteria	Unchlorinated B.coli	Chlorinated Bacteria	Chlorinated B.coli	Per cent reduction Bacteria	Per cent reduction B.coli
			Normal Sewage.				
3	5	1,343,000	82,000	176,000	42,000	88	48
5	9	1,186,000	50,000	13,200	1,400	99	97
7	2	1,640,000	505,000	9,600	10	99	99
			Sewage Containing Copper Wastes.				
3	18	72,000	320	13,700	160	81	50
5	12	192,000	5,400	8,700	380	96	93
6	11	55,000	13,200	4,500	2,130	94	84
7	15	154,000	9,300	1,700	230	99	98

Chlorination of Imhoff Effluent. The more complete removal of suspended solids in the case of the Imhoff tank treatment, and the fact that this treatment in itself eliminates a third of the total bacteria and three-fourths of the colon bacilli in the sewage, should favor chlorination of an effluent of this type. On the other hand the unstable organic bodies which result from septic action tend to use up a considerable proportion of the chlorine before it can act on the bacteria.

The results shown in Table XIX, are not sufficient for completely satisfactory conclusions. So far as the sewage containing the wastes are concerned there are samples enough to make it clear that while 3 parts of chlorine will not yield a satisfactory effluent, 6 parts will do so. A concentration of 5 parts was not studied. For the normal sewage even 6 parts did not attain our ideal standard of purification; only seven samples were examined, however, with this concentration. The amount of chlorine needed to produce a satisfactory effluent must, in any case, be determined by routine analyses in any plant constructed; but we may at least be certain

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that 5 parts of chlorine, and probably 6 or 7 parts, will be required for treating Imhoff effluent.

TABLE XIX. Results of Chlorination of Imhoff Effluent.

Chlorine p.p.m.	No. tests	Unchlorinated Bacteria	Unchlorinated B.coli	Chlorinated Bacteria	Chlorinated B.coli	Per cent reduction Bacteria	Per cent reduction B.coli
			Normal Sewage.				
3	6	2,360,000	20,000	1,020	7,000	99	65
6	7	570,000	19,000	138,000	3,040	76	84
			Sewage Containing Copper Wastes.				
3	2	540,000	550	270,000	500	50	9
6	51	111,000	2,030	11,300	750	90	62

Chlorination of Effluent from Activated Sludge Process. The effluent from activated sludge treatment is particularly amenable to further purification by the use of chlorine, since its original bacterial content should be already reduced and since its fully oxygenated condition leaves the chlorine free to exert a maximum disinfectant action. The activated sludge process, operated as we operated it, with a minimum degree of aeration, and acting on the abnormal East Street sewage, yielded only a moderately purified effluent. The total number of bacteria was actually increased in the case of the day flow containing the copper wastes; while the colon bacilli showed a 93 per cent reduction in the case of the normal sewage and 73 per cent reduction in the case of the sewage containing copper wastes. A further purification to the degree adopted as our standard was easily accomplished, however, by the addition of 3 parts of chlorine.

TABLE XX.

Results of Chlorination of Activated Sludge Effluent.

Chlorine p.p.m.	No. tests	Unchlorinated Bacteria	Unchlorinated B.coli	Chlorinated Bacteria	Chlorinated B.coli	Per cent reduction Bacteria	Per cent reduction B.coli
			Normal Sewage.				
2	16	564,000	16,700	122,700	1,433	78	88
3	3	257,000	400	8,400	400	97	0
			Sewage Containing Copper Wastes.				
2	34	497,000	3,000	98,500	980	80	67
3	4	426,750	300	8,300	550	98	0

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Conclusions in Regard to Chlorination. It appears evident that 3 parts of chlorine will yield fairly satisfactory results with the effluent of the activated sludge process; that 7 or 8 parts are needed for crude sewage; that 5 parts will probably suffice for screened sewage; and that, so far as the Imhoff effluent is concerned, 6 parts will not give satisfactory results as to total bacteria, but may yield an effluent which is low in colon bacilli.

In making our estimates as to the cost of chlorination combined respectively with fine screening and with Imhoff treatment, we have assumed, in the absence of more conclusive data, that 5 parts of chlorine will produce a satisfactory degree of purification in both instances, basing this assumption chiefly on the results of the colon tests which are of much more practical moment than the counts of total bacteria. It is evident, however, that this amount may very possibly have to be increased in practice, particularly in the case of the Imhoff effluent.

In the last three lines of Table XXI are shown for comparison the results obtained by the Miles acid treatment, which will be discussed in the succeeding section of this report. In both runs at East Street the results were eminently satisfactory, while with the Boulevard sewage the colon bacilli were not reduced to the desired level by the amount of acid used.

TABLE XXI. Bacterial Content of Final Disinfected Effluents.

			Bacteria		B.coli	
Type of effluent	Chlorine p.p.m.	No. tests	Average per c.c.	Per cent samples containing under 10,000	Average per c.c.	Per cent samples containing under 1,000
Crude sewage	3	69	87,300	41	22,000	57
	5	21	25,500	66	1,290	62
	7	21	16,500	62	1,170	76
	8	17	6,600	94	2,600	50
Screened sewage	3	23	49,000	32	9,350	68
	5	21	10,600	67	810	67
	6	11	4,520	85	2,130	46
	7	17	2,600	89	200	84
Imhoff	3	8	68,000	0	5,400	12
	6	58	26,600	27	1,030	77
Activated sludge	2	50	106,200	36	1,120	52
	3	7	8,340	57	490	57
Miles acid						
3d run	..	33	8,600	79	980	61
Do. 4th run	..	65	800	99	200	86
Boulevard	..	35	7,325	91	2,305	41

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RESULTS OF THE MILES PROCESS OF PRECIPITATION BY THE USE OF SULPHUROUS ACID WITH THE RECOVERY OF GREASE.

The disposal of city sewage has, in the past, always proved an expensive process,—in spite of the fact that such sewage contains materials which which have substantial value if they could only be recovered economically. Clark has estimated that the nitrogen in sewage would theoretically be worth $52 per million gallons, the fats $7, the potash $5, and the phosphorus, $4. A large proportion of these materials are not present however in an available form and the immense volume of water in which they are diluted makes their separation difficult and costly. Yet the hope that by improved methods these materials might be so economically recovered as to yield a profit, or at least pay a substantial part of the cost of necessary sewage treatment, has been constantly before the minds of sanitary chemists and engineers.

The sewage of Bradford, England, has for many years been precipitated with acid and grease recovered from the sludge with considerable financial success. The Bradford sewage contains a very large proportion of grease, derived from wool-washing establishments, and is therefore unusually favorable for such a process. The high prices brought by fat and glycerine since the war have, however, awakened interest in the possibility of applying similar treatment to ordinary city sewage, both in England and America. In this country attention has particularly been focused on a process of acid treatment patented by George W. Miles of Boston and reported upon two years ago by Professor R. S. Weston of the Massachusetts Institute of Technology (Weston 1916). The treatment consists in "the addition of an acid, to precipitate the bulk of the solids from sewage in the form of sludge which can be dried and degreased, thereby producing a readily salable and greaseless fertilizer, as well as recovering the valuable grease. Either sulphuric or sulphurous acid may be used and the process contemplates the manufacture of the acid at the disposal works. If sulphuric acid were chosen, ordinary weak chamber acid of 1.53 specific gravity would be used, but the cheapest source of acid is undoubtedly pyrite (native FeS_2) which, when roasted in a furnace of proper construc-

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tion, produces sulphur dioxide (SO_2). This is a gas which may be fed directly into the sewage, in which it would dissolve, forming sulphurous acid" (Weston 1916). The sulphur dioxide is a strong disinfectant and accomplishes a material disinfection of the sewage as well as considerable clarification. This process was studied in a series of tests by Mr. E. S. Dorr of the Sewer Division of the City of Boston between 1911 and 1914 and for a week in July, 1915, and three days in November, 1915, by Professor Weston.

An excess of acid was added to the sewage at all times in these Boston studies, this excess amounting to about 35 parts of SO_2 per million. The average amount of sulphur dioxid added per million gallons of sewage was 2300 pounds in the Dorr experiments and 1963 in those of Weston. The average detention period for subsidence is given by Weston as 7.7 hours. 13,400 pounds of wet sludge (85.8 per cent moisture) were obtained per million gallons by Weston, giving a dry sludge figure of 1909 pounds per million gallons, closely checking Dorr's figure of 1814 pounds, The grease in the sludge amounted to 22.66 per cent of the dry sludge or 430.1 pounds per million gallons of sewage, again closely checking Dorr's figure of 22.33 per cent and 436 pounds per million gallons respectively. The fat determined by Weston in the sewage amounted only to 36.8 parts per million, while the 430 pounds in the sludge is equivalent to 51.7 parts per million, the increase being attributed to the decomposition of soaps under the action of the acid.

Weston (1916) reports that his process reduces "the number of bacteria from millions to hundreds per cubic centimeter" and that "the sludge can be held at the works for four days during the heated season without giving off offensive odors, while the effluent is inoffensive and stable enough to be discharged into Boston Harbor without the slightest probability of creating a nuisance." He concludes "with the facts at hand, the process would be very satisfactory for Boston from a sanitary standpoint and is more promising economically than any other known."

While we scarcely hoped to obtain results which would warrant the expectation of a considerable net profit, such as was claimed at Boston, we felt that the Miles process deserved careful consideration in our New Haven studies. Conditions here

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seemed *à priori* unusually favorable to the process of acid treatment. It was desirable that the effluent to be produced should be clarified and disinfected, but not necessarily nitrified, precisely the results which the Miles process aims to produce; and the sewage at East Street was known to be of low alkalinity on account of the presence of acid wastes, which would of course diminish the amount of acid needed for neutralization.

Studies of Miles acid treatment were made, as described above, with the East Street sewage with its peculiar content of industrial wastes and also with the Boulevard sewage as a type of normal domestic sewage. Four different runs were made at East Street and one at the Boulevard, the length of the test periods ranging from 24 to 75 days. The tanks used for these experiments have been described on page 34. In all cases the acid was applied in the form of SO_2 gas and the acidified sewage was subjected to a four hour continuous flow detention period. Operation was continuous during each period and only at the end of a run was the sewage drawn down and sludge removed. Since the alkalinity of the East Street sewage was so very low (averaging only 50 parts for the four runs), it was necessary to add only 700 pounds of acid per million gallons of sewage treated to secure an acidity of 50 parts per million (as calcium carbonate). At the Boulevard sewer 1130 pounds of acid per million gallons of sewage were required to secure an acidity of 50 parts per million (as calcium carbonate).

General Results of Miles Acid Treatment. The general results of the acid treatment were highly satisfactory, as indicated in Table XXII. The effluent was well clarified and showed a good bacterial reduction. The removal of total suspended solids amounted to 61 and 66 per cent respectively at the two outfalls and the removal of settleable solids to 90 per cent.

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TABLE XXII. Chemical Results Obtained at New Haven Sewage Experiment Station with Miles Process of Treating Sewage.

(East Street Sewer.)

First run, June 2-25, 1917, inclusive, 25 days.
Second run, July 5-28, 1917, inclusive, 24 days.
Third test, Nov. 6-Dec. 19, 1917, inclusive, 44 days.
Fourth test, Jan. 18-Apr. 4, 1918, inclusive, 75 days.

	Chlorine	Alkalinity	Ammonia N	Nitrite, nitrate N	Suspended solids	Volatile suspended solids	Settleable solids	Turbidity
Raw Sewage								
Run 1	940	44	5.0	1.6	119	73	...	...
" 2	1022	57	4.6	1.5	92	57	2.20	...
" 3	1307	64	4.7	1.8	105	67	2.25	250
" 4	52	34	...	...	96	65	2.25	...
Average	830	50	4.8	1.6	103	65	2.23	250
Miles Effluent								
Run 1	...	-12	5.3	1.5	48	34	...	...
" 2	...	-92	4.8	1.6	37	28	0.10	...
" 3	...	-53	4.6	1.8	45	33	0.34	161
" 4	...	-99	...	...	32	23	0.21	...
Average		-64	4.9	1.6	40	30	0.22	161
Per cent reduction	...	...	0%	0%	61%	54%	90%	36%

(Boulevard Sewer.)

One test, March 25-April 21, 1918, inclusive, 28 days.

Raw sewage	46	126	15.6	...	120	84	1.99	...
Miles effluent	...	-105	11.2	...	40	33	0.19	...
Per cent reduction	...	...	28%	...	66%	61%	90%	...

All data p.p.m. except settleable solids which are in c.c. per liter.

The bacterial results obtained are shown in Table XXIII. In the Boston experiments reported by Weston an average count of 4,340,000 bacteria per c.c. (20° count) was reduced to 827 per c.c. by treatment with 2300 pounds of sulphur dioxide per million gallons of sewage. The results in Table XXIII obtained with 800 pounds of sulphur dioxide at East Street and 1483 pounds at the Boulevard, are less striking but on the whole very satisfactory. During the first run at East Street we added an insufficient amount of acid and the treated effluent had an average acidity of only 12 parts per million, many of the effluents being of course actually alkaline. Yet even in this case the re-

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moval of the total bacteria averaged 85 per cent and of *B. coli* types 98 per cent. Some effluents were alkaline even in the second run. The removal of total bacteria averaged 87 per cent in the second run, 98 per cent in the third and over 99 per cent in the fourth run, and in the Boulevard test. The removal of gas forming organisms was 89 per cent in the third run and over 98 per cent in all other cases. Of all samples of effluent examined at East Street 91 per cent showed less than 10,000 bacteria and 84 per cent less than 1000 *B. coli* per c.c., while at the Boulevard 91 per cent showed less than 10,000 bacteria and 41 per cent less than 1000 *B. coli* per c.c.

TABLE XXIII. Bacterial Purification Effected by Miles Acid Process.

Period	No. tests	Influent Bacteria per c.c.	Influent B.coli per c.c.	Effluent Bacteria per c.c.	Effluent B.coli per c.c.	Percentage reduction Bacteria per c.c.	Percentage reduction B.coli per c.c.
East St., 1st run, 6-2 to 6-24,							
Average for normal sewage	6	1,272,833	40,000	184,833	535	85	98
Average for sewage containing copper wastes	6	243,000	6,850	39,500	85	83	98
General average		766,249	23,425	112,166	310	85	98
2d run, 7-6 to 7-27,							
Average for normal sewage	8	1,391,909	165,454	208,006	124	85	99
Average for sewage containing copper wastes	15	133,013	1,402	558	93	99.6	93.3
General average		579,585	49,780	72,713	103	87	99
3d run, 11-6,							
Average for normal sewage	9	866,900	9,000	21,820	2490	98	89
Average for sewage containing copper wastes	24	142,000	9,100	3,700	410	97	92
General average		339,700	9,072	8,611	977	98	89
4th run, 1-19 to 4-4,							
Average for normal sewage	5	231,000	8,200	900	230	97	97
Average for sewage containing copper wastes	60	92,000	12,300	726	178	99	99
General average		130,384	11,984	759	182	99	98
Boulevard run	35	1,875,000	221,000	7,325	2305	99	99

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It is particularly important, from the standpoint of the practical sewage works operator, to note that both effluent and sludge were so affected by the acid present as to be stable for considerable periods, so that with a plant of this type no local nuisance need be anticipated. During the whole period of our experiments there were only one or two occasions on which slight signs of septic action were noticed in the tank and the sludge was stored in barrels for weeks without the production of offensive odors.

During the first two runs at East Street it was impossible to calculate the amount of SO_2 applied as the gas was generated by a sulphur burner and there was much loss from defective apparatus. In the later experiments in which the gas was delivered from cylinders of SO_2 gas, the pounds of SO_2 applied per million gallons of sewage were as follows: East Street, 3d run, 833; East Street, 4th run, 792; Boulevard, 1483. The average acidity of the effluent in parts per million was 12 for the first run at East Street, 92 for the second, 53 for the third, 99 for the fourth and 64 for the Boulevard run.

Studies on Plain Sedimentation. In a report on the Miles acid process presented by Goodnough and Clark in 1918 to the Massachusetts State Department of Health the results of acid treatment were compared with plain sedimentation, with the conclusion that the difference in results obtained was so slight as not to warrant the expense involved in the use of acid. These Massachusetts experiments were made on a small scale in bottles and an 18 hour sedimentation period was used, a procedure somewhat unfair to the acid process, which accomplishes the same results in four hours. The disinfection of the effluent and the freedom of the process from nuisance is of course ignored in such a comparison.

Nevertheless we thought it worth while to examine the comparative results of these two processes with our sewage and from August 17 to September 27, 1917, we operated the Miles acid tank as a plain sedimentation tank, using the same quantity of sewage and the same procedure in all respects except that the addition of acid was omitted. The results of this experiment are indicated in Table XXIV.

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TABLE XXIV. Results of Plain Sedimentation of East St. Sewage.

One test, August 14-September 27, 41 days.

	Rew sewage Parts per million	Effluent	Per cent reduction
Suspended solids	88	53	40
Alkalinity	68	88	Increase
Ammonia nitrogen	4.1	6.6	"
Moisture content, wet sludge	90.4%		
Wet sludge, pounds per million gallons	3135		
Dry sludge, pounds per million gallons	301		
Ether extract, dry sludge	19.6%		
Ether extract, pounds per million	58.7		
Nitrogen, dry sludge	1.52%		

According to these results, but 40 per cent of the suspended solids were removed from the sewage, as compared with 60 per cent by the Miles acid process. Septic conditions were pronounced in the tank, as the increase in ammonia nitrogen and alkalinity indicate. Bacterial determinations were not made during this test, but there is no reason to suppose that the count decreased to an appreciable extent, particularly in view of the offensive condition of the sludge.

The sludge was higher in moisture content than was the Miles sludge, and there was much less sludge and grease recovered. This was partly due to the low suspended solids in the raw sewage, but even if there had been 105 parts, as in the acid tests, instead of 88, the sludge and grease recovered would have been, respectively, 360 and 70 pounds. These quantities are 75 per cent and 58 per cent of the quantities recovered by the acid process.

Comparison of Results Obtained by Various Processes Studied. Table XXV shows the results obtained by plain sedimentation, sedimentation in the Imhoff tank, activated sludge treatment and the Miles acid process, at East Street, tabulated by months, and the general averages are summarized in Table XXVI. The results for June and July, 1917, in the case of the Miles process are for the first and second runs respectively, those for November and December for the third run and those for January to April, 1918, for the fourth run.

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TABLE XXV. Comparison of Results Accomplished by Various Processes Studied. Per Cent Purification.

	Ammonia N				Turbidity				Suspended Solids				Volatile suspended solids				Settleable solids			
Month	Sed.	Im.	Act.	Miles	Sed.	Im.	Act.	Miles	Sed.	Im.	Act.	Miles	Sed.	Im.	Act.	Miles	Sed.	Im.	Act.	Miles
June '17			20	–6							71	60			67	53				
July '17			20	–4							62	60			56	51			85	95
Aug. '17	0		16						42		63		35		60		89		90	
Sept. '17	–61		20		23		64		40		60		34		60		84		89	
Oct. '17			6				46				51				43				84	
Nov. '17		–32	7	2		9	62	28		47	67	56		41	63	51		82	95	85
Dec. '17		–6	12	4		22	31	43		47	50	55		38	40	48		82	82	82
Jan. '18		0	5	–7		11	15	46		45	39	53		43	39	52		85	53	94
Feb. '18										47	34	74		28	26	66		89	17	92
Mar. '18										40		63		39		61		43		85
Apr. '18										35		75		37		70		35		88
Average	–30	–12	13	–2	23	14	44	39	41	43	55	62	34	38	50	56	86	69	74	89

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Fig. XI.

GENERAL APPEARANCE OF IMHOFF (I), ACTIVATED SLUDGE (A) AND MILES ACID (M) EFFLUENTS, THE LATTER BEING THE CLEAREST OF THE THREE.

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It will be noted that with the particular sewage in question —which is so difficult to treat by biological methods—the Miles process gave a better purification as measured by removal of total suspended solids, volatile suspended solids and settleable solids than other methods of treatment. (See Fig. XI). Only from the standpoint of turbidity and ammonia did even the activated sludge process yield a superior effluent; and the superiority in this case was but slight.

TABLE XXVI. Comparative Results of Various Processes Studied. General Average.

	Ammonia N	Turbidity	Solids		
			Total suspended	Volatile suspended	Settleable
Wire mesh screens..	..	..	15	..	41
Plain sedimentation.	-30	23	41	34	86
Imhoff tank	-12	14	43	38	69
Activated sludge....	13	44	55	50	74
Miles acid process..	0	36	61	54	90

Deoxidizing Influence of the Miles Acid Effluent. The use of sulphur dioxide for the acidification of sewage in the Miles process has many advantages, but we have found that it may introduce an unforeseen complication into the scheme of operation. The sulphur dioxide applied first neutralizes the alkalinity, due to the bicarbonate of calcium, magnesium, sodium and potassium. The bicarbonates are changed to bisulphites. An excess of sulphur dioxide is of course necessary over that required for neutralization, and this excess goes into solution as sulphurous acid.

Both bisulphites and sulphurous acid are well known reducing substances, and on this account we thought they might be oxidized at the expense of the dissolved oxygen in the harbor water after the effluent had mixed with it. To test this point dilutions of effluent and harbor water were made and as soon as possible after dilution dissolved oxygen and sulphur dioxide were determined in the mixture, with the following results:

DEOXIDIZING EFFECT OF MILES EFFLUENT.

	Effluent	Harbor Water	1 Effluent 2 Water	1 Effluent 4 Water	1 Effluent 9 Water	1 Effluent 19 Water
Dissolved oxygen	0.8	12.0	1.0	5.0	8.8	11.0
Sulphur dioxide	118	0.0	8.0	0.0	0.0	0.0

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Thus, when samples of effluent containing 118 parts per million of sulphur dioxide were mixed with sea water containing 12 parts of oxygen they caused an almost instantaneous reduction of the oxygen content to 1 part in a mixture containing one-third effluent, to 5 parts in a mixture containing one-fifth effluent, to 8.8 parts in a mixture containing one-tenth effluent, and to 11 parts in a mixture containing only one-twentieth effluent.

Further experiments showed that sufficient oxygen would be taken from the diluting water to oxidize the total SO_2 in the effluent, both in bisulphites and in sulphurous acid, to SO_3. The total SO_2 content can be determined by means of a standard iodine solution, and from this the oxygen demand of the effluent may be calculated.

Our effluent was weakly alkaline, so that the amount of bisulphite present was relatively low, but in a sewage with high alkalinity the bisulphite would be relatively much greater than the sulphurous acid, and the total amount of SO_2 correspondingly greater than was found in the effluents produced from the East Street sewage. In general there may be present a distinct zone of deaerated water at the outfall of the effluent from the Miles process, and although this might not be objectionable from the standpoint of putrefactive changes, the destruction of higher plant and animal life in the water near an outfall might create serious problems.

In order to determine whether the sulphur dioxide might be oxidized before the effluent is discharged, an aerating tank was constructed as shown in Figure XII. This tank consisted of two superimposed concrete drain tiles, each 36 inches long and 30 inches in diameter. The air was distributed through a filtros plate which was cemented into an iron frame and was measured by means of a mercury manometer and an ordinary gas meter.

The first experiments were made on the fill-and-draw plan. The results of a typical experiment are shown in Table XXVII. These results show that the oxidation of the sulphur dioxide takes place quite rapidly, and that the quantity of air required is relatively very small. The effleunt, after 40 minutes' aeration, reduced the oxygen in a mixture of 1 effluent to 2 sea water from 14.2 to 11.8 parts per million, while before aeration it had reduced the dissolved oxygen in the mixture to 4.4 parts per million.

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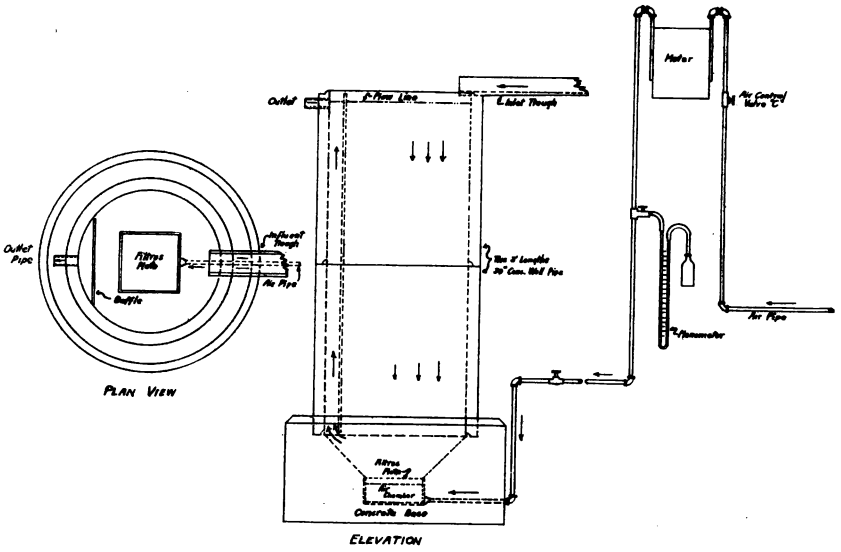

Fig. XII.

PLAN AND SECTION OF TANK USED FOR REAERATION OF MILES ACID EFFLUENT.

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TABLE XXVII. Aeration of Miles Effluent, March 4, 1918.

Quantity of effluent..... 220 gallons
Quantity of free air..... 25.5 cu. ft.

Time Miutes	SO_2 p.p.m.	Reduction per cent	Air cu. ft. per gal.
0	78.1	0	.000
10	71.7	8	.029
20	53.8	31	.058
30	23.0	70	.087
40	10.2	87	.116

Effluent mixed with sea water, before and after aeration, dissolved oxygen determined immediately.

Sample	Dissolved oxygen Before aeration	After aeration
Effluent	1.4	5.8
Sea Water	14.2	...
1 Eff. 2 Sea Water.....	4.4	11.8
1 Eff. 4 Sea Water.....	7.4	11.8

The tank was next used as an aerator on the continuous flow plan. The effluent from the Miles tank was passed through the tank as shown in the cut, the period of detention being 31 minutes. An average of 70 per cent reduction in sulphur dioxide was obtained by the use of .097 cubic feet of air per gallon of sewage. The results were quite similar to those obtained on the fill and draw plan with 30 minutes' aeration, with the exception that in the continuous flow experiments, 97,000 cubic feet of air per million gallons of sewage were required, as compared with 87,000 in the fill and draw experiments.

These quantities of air are relatively small, as compared with those used in the activated sludge process, and we believe the aeration and re-oxidation of the Miles effluent from the East Street sewage could be accomplished for less than $1 per million gallons if it were found necessary.

Experiments on the Dewatering of Sludge. The scale of our experiments was not sufficiently large to warrant extensive studies of the problem of de-watering sludge. Brief reference should, however, be made to a few tests conducted with a small centrifuge loaned to us for the purpose by the Tolhurst Company of Troy, N. Y., since they brought out certain points of general application to this process of de-watering.

The centrifuge in question was of the self-balancing type,

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with a 12-inch basket of solid bronze. This basket had a ring 1⅞" in diameter around the top, the space under this ring (.158 cubic foot) being filled with de-watered sludge, and the effluent liquor being thrown over the inner edge of the ring during operation. The rate of feeding the wet sludge regulated the solids in the effluent to some extent, but it would be impracticable to feed the sludge so slowly that the effluent liquor would be clear. The basket was driven at 2100 revolutions per minute, the sludge being fed into the basket through a funnel and hose.

The use of centrifuges for sludge drying is by no means new, the Dickson process in England making use of them successfully and the automatic Schafer-ter-Meer machines being in use at several cities in Germany. Centrifugal treatment has not been used to any extent in America in the past for de-watering sludge, as filter presses have been preferred in the few places where sludge is de-watered. Interest in centrifuges has been recently revived during experimental work on activated sludge at Cleveland, Ohio and Urbana, Illinois.

Our first experiment on this process was made with Miles sludge from East Street on December 22, 1917. Sludge was drawn from the tank and allowed to settle for a short time, the supernatant liquid being discarded. The sludge was then fed slowly into the centrifuge, 38 pounds in all being applied. A heavy cake built up around the periphery of the bowl in about fifteen minutes. The machine was then stopped and the cake removed. It weighed 5½ pounds. The effluent was very turbid and felt much more greasy than did the settled sludge. The following analyses were made of the sludge, the partially-dried cake and the effluent liquid.

Analyses of Wet Sludge, Cake and Effluent from Centrifuge.

	Specific gravity	Moisture	Volatile matter Dry sludge	Grease (Ether extract)
Sludge	1.034	87.7	70.0	41.7
Cake	1.167	64.3	48.4	12.7
Effluent	1.003	93.4	75.4	44.6

The results were rather surprising, as there was marked segregation of the grease, the cake containing less than one-third as much as was contained in the sludge treated, the effluent

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being correspondingly higher in grease than was the sludge. The cake was unlike the sludge in appearance and physical condition, being lighter in color and more crumbly when dry. This experiment demonstrated that a good cake could be produced from the Miles sludge by centrifugal treatment, but that the effluent would be so turbid that it could not be discharged into any diluting water, while practically all of the grease would be carried to waste in this effluent liquid. Another experiment gave the following results:

Analyses of Wet Sludge, Cake and Effluent from Centrifuge.

	Specific gravity	Moisture	Volatile matter	Grease (Ether extract)
Sludge	1.047	84.1	65.8	27.7
Cake	1.135	64.8	51.7	10.9
Effluent	.943	89.8	81.9	46.1

The results noted in the previous experiment were even more marked in this one. It was thought that a separation of mineral oil from vegetable and animal grease might possibly be effected by proper manipulation of the centrifuge if they were not homogeneous in the sludge, but analyses of the grease showed 32.6%, 32.8% and 31.8% of unsaponifiable matter in the grease from the wet sludge, cake and effluent respectively, so that this process apparently offered no hope of removing the worthless mineral oil from the more valuable grease.

Another experiment was made using a perforated bowl lined with a filtering felt. It was thought if the liquid were thrown out by filtering through this felt instead of over the rim, the grease might be caught in the sludge cake and not lost. This hope was not realized, however, as the greasy sludge quickly clogged the filtering felt, and after this had occurred the bowl acted just as did the imperforate type.

It therefore appears that centrifuges are not adapted to the treatment of Miles acid sludge.

Two experiments were made on centrifugal drying using settled activated sludge, the results of which are given below. The first test was made with the imperforate bowl, the second with the perforated bowl.

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Centrifugal Treatment of Activated Sludge.

	Imperforated bowl		Perforated bowl	
	Sp. Gr.	Moisture	Sp. Gr.	Moisture
Wet sludge.....	1.043	91.7	1.017	94.4
Cake	1.078	75.9	1.071	71.1
Effluent	1.004	98.9	1.000	98.9

These experiments showed that our activated sludge could be de-watered to 76 per cent moisture by means of centrifuges, but that the effluent was very turbid and would have to be re-treated. If the activated sludge process had been chosen for this sewage, however, it is possible that centrifuges might have been preferable to filter presses for de-watering the sludge. The moisture content of the sludge cake is much lower than has been obtained on activated sludge at other places, although this may partly be due to the dryness of the settled sludge treated.

Drying Miles Acid Sludge. The experiments at East Street showed that 450 pounds of dry sludge could be obtained per million gallons of sewage. Sludge, as dried for commercial purposes, however, is allowed to contain a maximum of 10 per cent moisture when used as fertilizer, so that 500 pounds of sludge would be produced commercially per million gallons of sludge.

Sludge might practically be dried to this low moisture content, either by direct drying of the wet sludge as taken from the tanks at 85 per cent moisture, or by de-watering to 65-70 per cent moisture by some mechanical method and heat drying for the removal of the rest of the moisture. We have dealt in the preceding section with one method of de-watering the sludge, by means of centrifuges, and our results showed that this method would not succeed. Practically the only other method of de-watering available is by means of filter presses. We were not able to run experiments on the pressing of Miles sludge, but at best filter presses will hardly do better than reduce the moisture content from 85 to 65 per cent. We have calculated in Table XXVIII the cost of coal required to dry Miles acid sludge from East Street to 10 per cent moisture. Coal is figured at $7.50 per ton, and one pound of coal is assumed to evaporate seven pounds of water.

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TABLE XXVIII. Cost of Coal Required for Drying Wet Miles Acid Sludge, East Street Sewer, to 10 Per Cent Moisture.

Moisture	Water Evap'd Pounds per m.g.	Coal Pounds per m.g.	Costper m.g. (500 lbs. sludge)	Cost per ton 10% sludge
95%	8500	1214	$4.55	$18.20
90%	4000	572	2.15	8.60
85%	2500	357	1.34	5.36
80%	1750	250	.94	3.76
75%	1300	186	.70	2.80
70%	1000	143	54	2.16
65%	785	112	.42	1.68

From this table it appears that it would require $5.36 worth of coal to dry one ton of sludge from 85 per cent moisture, and $1.68 worth from 65 per cent moisture. If filter presses will de-water the wet sludge to 65 per cent moisture for less than the difference between these costs, it would be advisable to interpose this intermediate step between the wet and dry sludge. In view of the fact that we have no data as to whether filter presses will handle this sludge, however, we have made our cost calculations on the assumption that the 85 per cent sludge would be dried in direct-heat dryers, just as taken from the tanks.

Amount and Character of Grease Recovered by the Miles Acid Process. The failure of centrifugal treatment to de-water Miles sludge successfully is of course no argument against the acid treatment itself. Direct heat drying would no doubt operate successfully and would probably prove the most satisfactory process if the acid treatment should prove in general efficient and economical. That it is efficient seems reasonably clear; but its economic practicability depends on the value of the grease to be recovered from the sludge. In the Boston experiments reported by Weston 1800-1900 pounds of dry sludge per million gallons of sewage were obtained and of this material 22-23 per cent was grease, the yield of grease per million gallons of sewage treated varying from 430 to 436 pounds. The sludge had a low moisture content (85.5 per cent). E. S. Dorr, who conducted the first Boston experiments, estimated the value of grease present at $15.08 and the value of the fertilizer base at $9.25 per million gallons of sewage treated. With an estimated cost of $18 per million gallons for treatment this would yield

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a net profit of $6 per million gallons. Prof. R. S. Weston believes that this estimated margin of profit is too high, but "is unable, by reasonable comparison with analogous cost data from other sources, including his experience, to wipe it out."

The information obtained in our New Haven experiments in regard to the amount and general character of the Miles acid sludge is presented in Table XXIX:

TABLE XXIX. Character of the Miles Acid Sludge.

	East Street Sewer				Boulevard Sewer
Length of run	25 days	24 days	44 days	70 days	29 days
Total gallons sewage treated	260,000	239,400	407,820	602,220	145,500
Pounds wet sludge per m.g. sewage	3,750	4,025	3,200	2,600	5,375
Specific gravity	1.067	1.048	1.054	1.061	...
Per cent moisture	86.6	88	86.3	85.7	92.5
Pounds dry sludge per m.g. sewage	503	483	439	368	403
Ether extract, per cent dry sludge	23.7	24.0	29	32.6	30.9
Ether extract, pounds per m.g.	119	116	127	120	124
Volatile matter, p. c. dry sludge	47.2	51.2	57.3	63.8	78.5
Nitrogen, per cent dry sludge	1.6	1.6	2.4	2.0	3.0

In comparing these results with those of the Boston experiments, it will be noted that the yield of sludge was less than one-fourth of that recorded at Boston, but this was to be expected since the New Haven sewage is a weak one and the amount of acid needed for precipitation was correspondingly reduced (at least with the East Street sewage). The moisture content of the New Haven sludge was not quite so low as that obtained in Boston, but showed an even higher grease content, exceeding 30 per cent of the dry material in two of the tests.

So far the results of the New Haven experiments were very favorable to the Miles process; but when the grease which had been removed was studied with more care in order to determine its real commercial value the aspect of the matter began to change. The difficulty lies primarily in the presence of a large proportion of unsaponifiable material (waxes, mineral oils and similar substances) in the ether extract, substances of this kind being practically worthless and their presence necessitating costly processes of purification. The sludge obtained from the third 44-day run when analyzed by Dr. Raymond Wells yielded 24 per cent of grease, 46 per cent of tankage and 28 per cent of water. The grease analyzed as follows:

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Moisture and volatile matter	11.0
Unsaponifiable material	21.1
Free fatty acids (by weight)	40.2
Neutral grease	22.3
Insoluble and metallic soap	3.3

Of the 40.2 per cent of free fatty acids 14.4 per cent was rosin and 25.8 per cent actual free fatty acids.

The de-greased sludge contained 3.91 per cent of nitrogen as NH_3, .96 per cent of phosphoric acid as P_2O_5 and 51.88 per cent of ash.

The grease obtained from the other three runs made with the East Street sewage contained respectively, 19.8 per cent, 20.7 per cent, and 28.3 per cent of unsaponifiable material.

In view of the fact that the East Street sewer receives contributions of mineral oil from a munition factory it was thought that the large amount of unsaponifiable material might be due to this cause and the Boulevard plant was installed to test this point on a sewer which carries a fairly normal domestic sewage. The result here was distinctly better, the proportion of unsaponifiable material being only 15.7 per cent with 41.5 per cent free fatty acids, 0.5 per cent moisture and volatile matter and 1.3 per cent insoluble impurities. Even this value is still so high as seriously to impair the value of the grease.

It seems probable that a fairly high content of unsaponifiable material is a normal characteristic of grease obtained from sewage sludge. Thorpe in his Dictionary of Chemistry says "sewage fats are characterized by large proportions of free fatty acids. The amount of unsaponifiable matter is also considerable. The nature of this has not yet been investigated. Probably it consists to a large extent of coprosterol which forms an important constituent of excrementitious matter." Lewkowitsch in the Technology and Analysis of Oils, Fats and Waxes notes the presence of 11.6 per cent of unsaponifiable material in the grease obtained at Cassel. The source of this material is apparently the feces themselves, for a review of the literature shows that of the ether extract of dried feces (which amounts to 27-35 per cent) 12-14 per cent is unsaponifiable matter, about half of the latter perhaps being cholesterol.

Value of Products Obtained from the Miles Acid Process. The usual limit for unsaponifiable matter in grease to be used for

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soap making is about 5 per cent, and unless grease containing 10-20 per cent of material of this kind could be economically distilled it could be used only as wool grease, which is worth about half as much as garbage grease or 5-6 cents a pound according to the high prices of 1918. Samples of the sludge obtained from New Haven sewage were submitted to Colgate and Company and the Cobwell Corporation of New York and to Swift and Company and Armour and Company of Chicago and the chemists of all these concerns, after extracting the grease and studying it, were of the opinion that in its crude state the material was of practically no value to a soapmaker. If such grease is to be utilized it must be first freed from its impurities by distillation.

Through the courtesy of Mr. C. E. Eaton of William M. Ware and Company of Boston we were put in contact with a firm of grease distillers, the Falk Company of Pittsburgh. Mr. P. F. Wild, Vice-President of the Falk Company, arranged to distill a 4 pound sample of the grease obtained from the Boulevard sewage. The material was saponified and then decomposed and the fatty acids obtained were distilled. The product which resulted was light brown in color but had a noticeable odor, altho the chemist of the Falk Company reported that it was much less offensive than garbage grease. He added that the grease "can be worked in practical manner if the sulphurous fumes which are in combination with the oil can be removed. Otherwise during distillation this considerable sulphurous acid involved is more or less destructive to the apparatus used, and imparts a rather disagreeable odor during the distillation."

The distilled grease thus obtained amounted to 70 per cent of the crude grease which yielded in addition 3 per cent of glycerine and 22 per cent of pitch.

According to the estimate of William M. Ware and Company the crude product as obtained from the Boulevard sewage should be worth 8.5 cents a pound, and the grease from the East Street sewage (containing 25 instead of 15 per cent of non-saponifiable matter) not over 6.5 cents. The ether extracts obtained from both sewages varied, as determined in the laboratory (see Table XXIX) between 116 and 124 pounds per million gallons, but the extractions made for us by the Cobwell Company and the Colgate Company indicate that not more than 100 pounds could be safely assumed on

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a commercial scale in either case. On this basis the Boulevard grease would be worth perhaps $8.50 per million gallons. The grease-free tankage corresponding to 100 pounds of grease per million gallons would amount to 300 pounds for the Boulevard sewage. This grease free tankage contained 4.8 per cent of ammonia worth at $4.00 a unit (20 cents a pound) $2.88 per million gallons. The Boulevard sewage would therefore yield products worth altogether $11.38 per million gallons.

Our data in regard to the grease obtained from the East Street sewage are less satisfactory, since this material was not distilled on a commercial scale. Dr. W. S. Richardson of Swift and Company, and Dr. Paul Rudnick of Armour and Company believed the crude product to be practically unsalable. Dr. M. H. Ittner of Colgate and Company found 20 per cent of unsaponifiable material in his samples and emphasized the fact that the grease would have to be distilled and would probably yield less than 60 per cent of fatty acids. Mr. G. A. Molleson of Kuh and Valk, grease brokers of New York City, considered the grease as submitted to him to be unsalable and suggested that if the total of moisture, volatile matter and unsaponifiable matter could be brought below 20 per cent it might be worth 5-6 cents. Dr. Raymond Wells of the Cobwell Corporation thought that even for use as wool grease distillation would be necessary and that some of the mineral oils present in this sample might possibly go over in the distillate making even the distilled product unsuitable for soapmaking. He thought 5-6 cents a pound would be as much as the grease was worth. He noted also that the composition of the sludge was such as to promise certain difficulties in extraction if the process were not carefully controlled. Dr. Rudnick had the same experience, reporting clogging and difficulty in the separation of the finely divided sludge from the gasoline extract. He also noted that the dried tankage obtained was objectionably fluffy.

Altogether, in view of the peculiarly unfavorable characteristics of this particular sludge we do not believe it would be safe to assume a value for the crude product of more than 5 cents per pound. This estimate, however, we feel is not too high in view of the possibility of distilling the grease and its suitability for wool grease if not for soapmaking. This would amount to a return of $5.00 per million gallons.

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The East Street sewage should yield 350 pounds of tankage per million gallons but its tankage contains only 3 per cent of ammonia, giving a tankage value of $2.09 per million gallons, which with a grease value of $5.00 would give a total return of $7.09.

CONCLUSIONS IN REGARD TO THE DISPOSAL OF THE SEWAGE FROM THE EAST STREET OUTFALL.

Of the various processes available for the treatment of city sewage it is obvious that any form of filtration would be out of the question for a disposal plant located at the East Street outfall. Our studies have indicated that activated sludge treatment cannot be considered on account of the presence of industrial wastes which prevent the bacterial activities upon which this method of treatment depends. In order to secure the end results desired, a substantial removal of suspended solids and a reasonably high degree of bacterial purification, there remain three possibilities, fine screening followed by chlorination, Imhoff tank treatment followed by chlorination, and the Miles acid process. It has been pointed out above that fine screening gave us a removal of suspended solids which we did not consider adequate for the protection of the harbor; and that the character of the sludge formed in the Imhoff tank was so abnormal as to threaten the possible production of a local nuisance. We have nevertheless given careful consideration to all three of these processes and have prepared for each of them preliminary cost estimates which are shown in Table XXX.

The estimates are based on the production of SO_2 gas by burning sulphur (assumed to cost $36 a long ton) and on drying from 85 to 10 per cent moisture (coal assumed at $7.50 per ton). We have estimated a very high cost for the construction of Imhoff tanks ($20000 per million gallons) on account of peculiar local conditions at the outfall, since the tanks would have to be built for the most part below tide water. The cost of chlorination is based on the use of five parts of available chlorine per million parts of sewage, an amount which we have found essential for the treatment of either screened or clarified sewage. It is very probable that in actual practice more than 5 parts might be necessary.

It appears from these estimates that the acid treatment of the sewage from the East Street outlet should be materially cheaper than

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either the Imhoff treatment or fine screening, under existing local conditions. With a fall in the price of grease after the war the outlook would be less favorable. Even if all revenue from the sale of grease and fertilizer were eliminated however, the cost would not be very much greater for acid than for Imhoff treatment. Other conditions make the case for the Miles process at the outfall almost irresistible. Our studies have shown that fine screens will remove only a small proportion of the suspended matter from either the East Street or the Boulevard sewers, and we are of the opinion that the purification so effected would not be adequate to prevent sludging in the dredged channel into which the effluent must be discharged. On the other hand our experiments with Imhoff treatment of the East Street sewage have been most unpromising. The tank studied produced a fairly satisfactory effluent but the sludge was highly offensive and never attained the normal character of Imhoff sludge, on account of the antiseptic action of the copper present in the sewage.

TABLE XXX. Estimated Cost of Treatment of East Street Sewage. Dollars per Million Gallons.

	Miles Acid Process	Imhoff Tanks and Chlorination	Fine Screens and Chlorination
Tanks and buildings (interest and depreciation)	2.47	5.28	4.60
Acid treatment	6.93		
Drying sludge	2.09		
Degreasing sludge	1.78		
Redrying tankage	.17		
Superintendence	1.06	.46	.46
Labor on tanks and screens	1.00	1.20	1.42
Disposal of sludge or screenings		1.00	.50
Chlorination		4.05	4.05
Gross cost	15.50	11.99	11.03
Revenue	7.09		
Net cost	8.41	11.99	11.03

*No allowance has been made in these estimates for royalties on the Miles acid process, which is a patented one. Assurances have however been obtained from the Miles Patents Co. that such charges would be reasonable. This item should be an insignificant one as compared with the total cost of construction.

Above all, however, the thing that counts most heavily in favor of the Miles process under the conditions obtaining at New Haven, is its freedom from nuisance. If heavy costs for interceptors and pumping are to be avoided, the sewage of the city must be disposed

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of at four different points, all of them in thickly settled areas where offensive odors must be prevented at all costs. Furthermore the problem of disposal of sludge and screenings would present peculiar difficulties. A process of treatment which should be free from local nuisance and which wholly eliminates the problem of sludge disposal is the ideal one for such a local condition.

CONCLUSIONS IN REGARD TO THE DISPOSAL OF THE SEA STREET, MEADOW AND STATE STREET, JAMES STREET AND POPLAR STREET SEWAGES.

Aside from the short series of screening tests and a month's operation of the Miles acid process on the Boulevard sewer, we have conducted no experimental work on the sewage discharged from the other main outfalls of the city. We know, however, from Mr. Harrub's survey and from analyses of sewage from the other outfalls made under direction of Prof. S. E. Barney, that the sewers of New Haven, aside from that at East Street, carry a fairly normal flow of domestic sewage. From the conditions of the case the processes likely to prove successful are limited to the same three combinations tested at East Street; and we know pretty well what fine screening and Imhoff treatment are likely to accomplish with an average American domestic sewage. Activated sludge treatment could no doubt be applied successfully to such sewages as those in question, but the operation of four small units of this type would certainly be expensive, since the cost of power in New Haven is high and the sewage of the city is in general so weak that a relatively small revenue could be estimated from the recovery of nitrogen in the sludge.

In order to obtain an idea of the relative cost of the three processes which seem most suitable for local conditions we have prepared in Table XXXI preliminary estimates for the treatment of the sewage of the Sea Street outfall, based on our studies of its principal tributary, the Boulevard sewer. These figures should be fairly typical for the other New Haven outfalls.

The Miles process in this case is considerably more expensive than at East Street, first because of the higher alkalinity of the sewage, and second because of the fact that the plant would be smaller (six million gallons) and costs per unit volume therefore larger. In particular the cost of superintendence rises to a high

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figure since we are convinced that a chemical industry of this nature can not be carried out without expert guidance. The expense of Imhoff treatment is slightly higher for the same reason, in spite of the lower construction costs.

The same objections which militate against screens at East Street limit the promising possibilities at the Sea Street sewer to Imhoff and acid treatment. The acid treatment shows a lower net cost and would be freer from nuisance. On the other hand the gross cost of the Miles process is very high and with a new procedure of this sort, never yet applied to purely domestic sewage on a practical scale, it must be recognized that many factors, such as the difficulties in distillation and the deoxidation of diluting water caused by the contained chemicals, may cut heavily into the assumed revenue.

If the problem of the Sea Street sewer stood by itself we should be somewhat in doubt whether to favor Imhoff or acid treatment, with the facts in hand. Since, however, the case for acid treatment seems so clear for the East Street sewer we are of the opinion that it would be wise to delay construction at other New Haven outfalls until the acid process has been tried out on a practical scale at the point where it promises best results. If an acid treatment plant at East Street is successful the drying and de-watering of the sludge from this and other plants could be conducted at one central location, the costs cited in Table XXXI would be materially reduced, and acid treatment might well prove economical for all the main outfalls of the city. It is quite probable, too, that the Boulevard sewer at least may in the future receive considerable amounts of industrial wastes, since the district is one well suited for industrial development. If this were the case the same arguments which have militated against Imhoff treatment at East Street might operate in the case of the Boulevard sewage.

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TABLE XXXI. Estimated Cost of Treatment of Sea Street Sewage. Dollars per Million Gallons.

	Miles Acid Process	Imhoff Tanks and Chlorination	Fine Screens and Chlorination
Tanks and buildings (interest and depreciation)	2.47	4.44	4.50
Acid treatment	10.74		
Drying sludge	2.04		
Degreasing sludge	1.91		
Redrying tankage	.17		
Superintendence	2.65	1.15	1.15
Labor on tanks and screens	1.00	1.50	2.05
Disposal of sludge or screenings		1.00	.50
Chlorination		4.05	4.05
Gross cost	20.98	12.14	12.35
Revenue	11.38		
Net cost	9.60	12.14	12.35

SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS.

As a general result of our investigations we have reached the following conclusions:

1. The present method of discharging the untreated sewage of New Haven from outfalls above low tide level is already productive of serious nuisance. It renders the taking of shell fish within the limits of the harbor unsafe and constitutes a menace to the health of those who use the harbor waters for bathing. These conditions are becoming intensified year by year, with the increase of the sewage flow and are bound before long to become intolerable.

2. The only way in which gravely offensive conditions can be avoided on the flats which make up the greater portion of the harbor is by the construction of outfall sewers discharging, through submerged outlets, directly into the harbor channels.

3. In order to avoid deposition of sludge in the channels and possible overtaxing of the digestive capacity of the harbor waters, it is essential that a substantial proportion of the suspended matter in the sewage should be removed before it is discharged in the manner specified.

4. In order to protect the local shellfish industry, and the bathing beaches in the vicinity of New Haven, the sewage must be so treated as to secure a high degree of purification as regards intestinal, and potentially disease-producing, bacteria.

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5. The fact that disposal plants must be located in thickly settled districts makes filtration processes out of the question, and renders it necessary to take extreme precautions against the production of offensive odors in the vicinity of the plants.

6. The disposal of sludge or screenings from disposal plants located at the points indicated would be attended with unusual difficulties.

7. Treatment of the sewage by fine wire mesh screens or plate screens would not be adequate for the removal of suspended solids rendered necessary by local conditions.

8. The operation of Imhoff tanks or of the activated sludge process, or of any other method of sewage treatment which depends on biological activity, would be seriously interfered with, in the case of the East Street sewer, by the presence of antiseptic industrial wastes.

9. For the treatment of this industrial sewage at the East Street outfall the Miles acid process appears to be the only one reasonably certain to secure the necessary results without danger of the production of a local nuisance.

10. For the treatment of the sewage from the other outfalls, either the Miles acid process or Imhoff treatment followed by chlorination should yield satisfactory results.

11. The Miles acid process, with a fair allowance for revenue to be obtained from the recovery of the grease and fertilizing materials, should prove materially cheaper than any other available method of treating the East Street sewage; and it would probably be somewhat cheaper than alternative procedures at the other outfalls of the city.

We therefore recommend that detailed plans and estimates be prepared for a Miles acid treatment plant at the East Street outfall; and that this installation be completed as soon as possible. If operation of the East Street plant proves economical the same system should be extended to the other outfalls. If it does not, Imhoff treatment, followed by chlorination, should be adopted for the treatment of the sewage from Sea Street, Meadow and State Streets, James Street and Poplar Street.

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